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National Highway Traffic Safety Administration

Systems Analysis Approach to Restraint Systems Integration—Sled Test Support

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15. Supplementary Notes

16. Abstract

This report covers the final phase of a three phase program whose overall objective was to demonstrate the validity of the systems analysis approach to restraint systems development.

The term "systems analysis approach" is used to convey the concept of using high speed computing techniques to design and integrate airbag restraint systems into the subject vehicle in a way that is optimally compatible with its crash environment. If successful, the necessity of conducting a large number of preliminary tests prior to converging to the final design will be minimized since the many interrelated parameters that affect restraint system performance can be investigated in a highly efficient manner through computer simulation.

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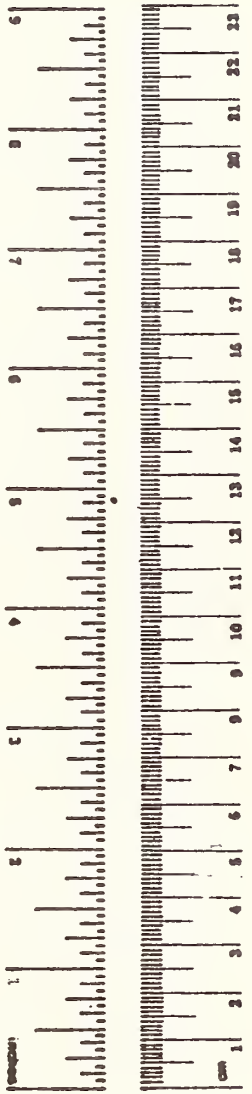
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

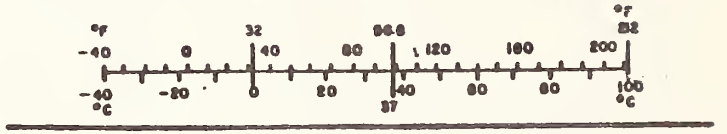
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. Mr. Bill Peterson of NHTSA Vehicle Research and Test Center in East Liberty, Ohio and Mr. Bob Esser of the same facility for their invaluable help during the sled test phase.

2. Mr. Joseph (Buck) Penrose of Delorean Motor Company for his prompt help in obtaining the necessary test hardware and engineering drawings.

3. Mr. David Biss (formerely of NHTSA) who as CTM provided us with the guidance and day-to-day information needed to make the program the success it turned out to be.

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1.0 BACKGROUND

This report is the final report for Contract No. DTNH22-82-C-07132, "Systems Analysis Approach to Restraint Systems Integration - Sled Test Support". It is also the report which covers the final phase of a three phase program initiated in March of 1981 whose overall objective was to demonstrate the validity of the systems analysis approach to restraint systems development. For the sake of continuity and to provide the reader with the background necessary to best understand this report, the pertinent information from the preceding two phases will be briefly described. Following this we will discuss the results of this third and final phase in detail.

1.1 Phase I - Contract No. DTNH22-81-C-07330

In March of 1981, Fitzpatrick Engineering was awarded a contract by NHTSA to use a "systems analysis approach" to integrate preliminary versions of a driver and passenger airbag system into a production ready, small car.

The term "systems analysis approach" is used to convey the concept of using high speed digital computing techniques to design and integrate airbag restraint systems into the subject vehicle in a way that is optimally compatible with its crash environment. If successful, the necessity of conducting a large number of preliminary tests prior to converging to the final design will be eliminated since the many interrelated parameters that affect restraint system performance can be investigated in a more efficient manner. This method has the potential of being more efficient since not only will less

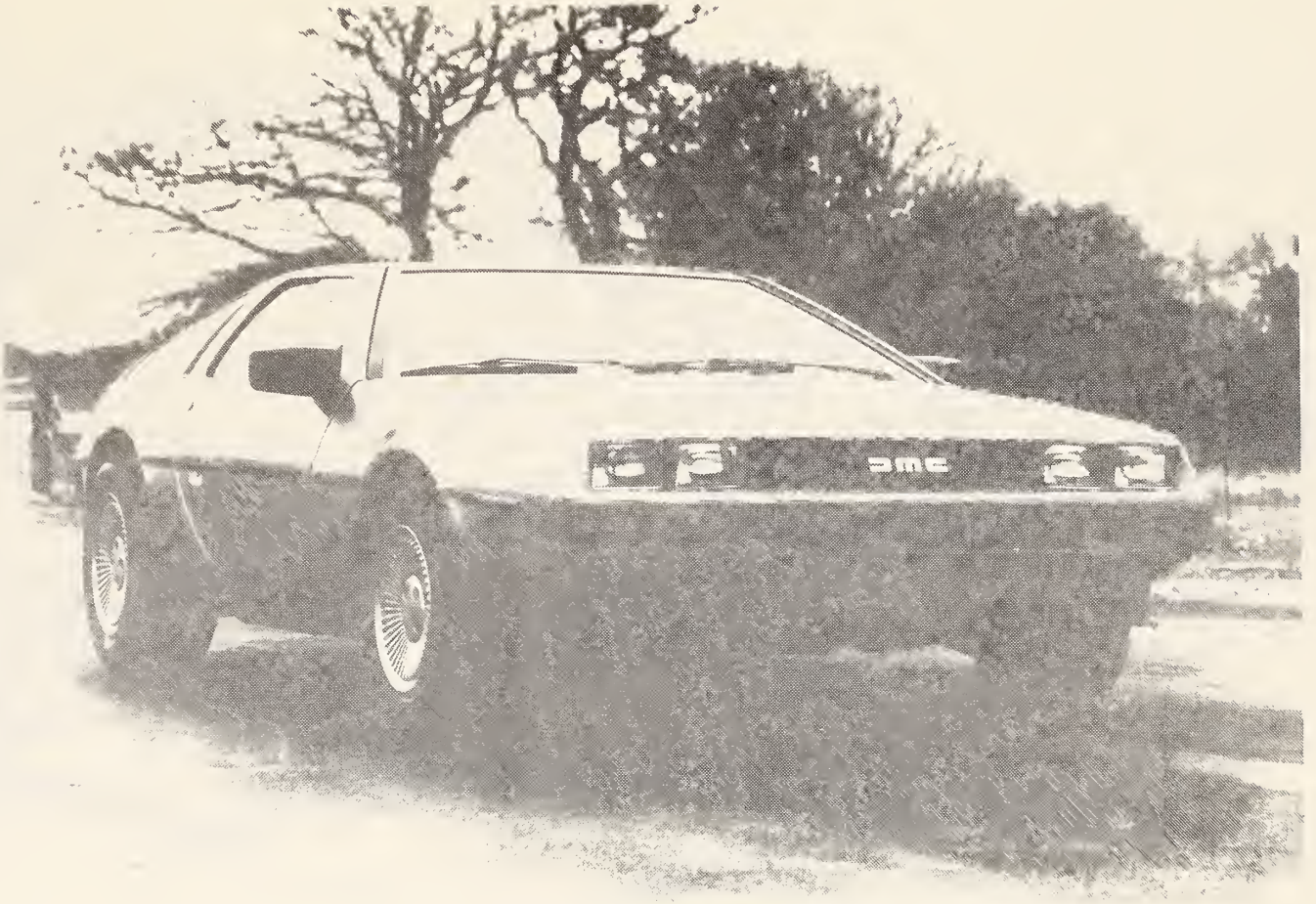
testing be required with its corresponding savings in time, but also the cost required for the computer approach should be much less than what might be spent for a trial and error approach based upon a large number of rather expensive tests.

The reason for using a "production ready, small car" was two-fold. First, there is a need to demonstrate that the restraint system design which evolves through the systems analysis approach will perform effectively in a structurally unmodified, production car. Second, the car should weigh less than 3000 lb to reflect the current trend toward the smaller average vehicle in the traffic mix.

Although the approach taken in this program would apply equally to any small car, a vehicle had to be chosen to demonstrate the systems analysis approach. The vehicle chosen was the DeLorean sports car. This vehicle is a two-passenger, rear engine car with gull wing doors and a stainless steel exterior skin as shown in Figure 1-1. The main structural frame is constructed of steel and roughly resembles an "X" with the middle of the X comprising the center spine that runs through the passenger compartment. Figure 1-2 shows this X-frame. Fastened to this main X-frame is a fiberglass body constructed of glass reinforced panels and foam filled beams as shown in Figure 1-3. The vehicle curb weight is approximately 2700 lb.

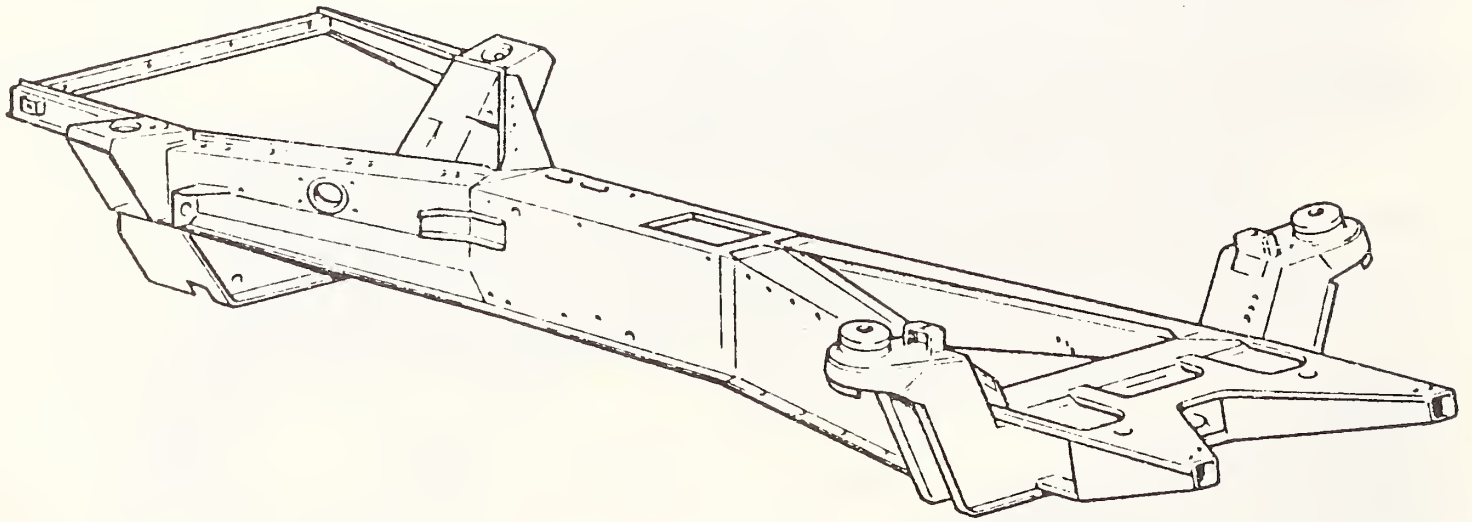
Fitzpatrick Engineering's main tasks in Phase I were to:

a) Design a preliminary driver and passenger airbag restraint system using computer techniques.



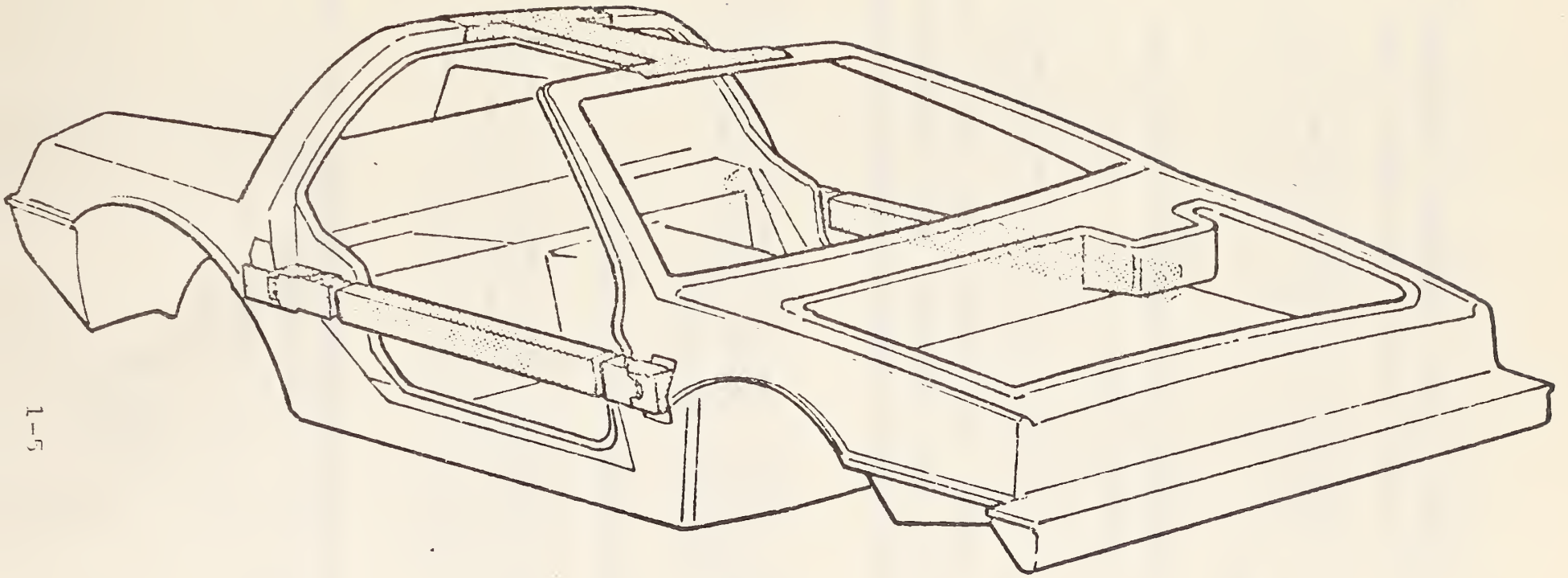
DeLorean Sports Car

Figure 1-1



DeLorean "X" Frame

Figure 1-2



DeLorean Fiberglass Underbody

Figure 1-3

b) Specify the restraint system components to be used in the two barrier crash tests scheduled for Phase I.

c) Direct the test contractor, Dynamic Science, on the installation and integration of the restarint systems into the DeLorean.

d) Perform as Engineering Test Director for the two frontal barrier crash tests.

The purpose of these two Phase I crash tests was to determine the structural response of the DeLorean at two different crash speeds so as to have the necessary input for the Phase II computer simulations and to provide an early indication of the performance potential of the computer derived restraint systems.

In the pre-crash test computer simulations using the DRACR and PAC computer models of the driver and passenger interaction with airbag restraint systems we:

a) Chose the airbag shapes and volumes.

b) Evaluated eight different passenger inflators (including the possibility of using two "driver type" inflators instead of a single cylindrical, "passenger" type inflator).

c) Evaluated the restraint system performance at 10 and 15 msec sensing times to determine crash sensor specifications.

d) investigated the effect of staging the "driver type" inflators simulated for the passenger system to select the inflator configuration that would optimally satisfy the requirements of the forward positioned child as well as the normally seated adult.

The result of these computer simulations was a preliminary restraint system design for the driver and right front passenger which was then converted to engineering drawings and specifications and ultimely procured for the two crash tests. The latest versions of these preliminary systems will be described later in Section 2.0

The two crash tests were conducted on September 24, 1981 and October 15, 1981. The first test was conducted at 36 mph and the second test at 40.6 mph. Both tests were frontal barrier tests.

The report written at the conclusion of Phase I contains the details of these tests; suffice it to say here that the results were very encouraging in that all of the injury measures for the driver and passenger in both tests were well below the criteria limits. This was our first confirmation that the systems analysis approach to restraint system design and integration via computer simulation has great potential.(Table 1-1 shows a summary of the injury measures for these two crash tests with the Phase I restraint systems design.)

1.2 Phase II - Contract No. DTNH22-81-C-07557

In the Phase I study, emphasis was placed upon the use of computer simulations and past experience to rapidly converge

Table 1-1

Injury Measure Summary

DeLorean Crash Test No. 1

36 MPH Frontal Barrier Test

Injury Measure	Driver	Passenger	"208" Limit
HIC	404	371	1000
Peak Res. Chest G's (-3 msec.)	44	42.5	60
Femur Loads -Lbs			
Right:	1125	1050	2250
Left:	840	*1750(1220)	2250

DeLorean Crash Test No. 2

41 MPH Frontal Barrier Test

Injury Measure	Driver	Passenger	"208" Limit
HIC	366	684	1000
Peak Res. Chest G's (-3 msec)	46	52.5	60
Femur Loads - Lbs			
Right:	1220	1160	2250
Left:	920	*2110(1150)	2250

*Noise spike (actual value in parenthesis)

to a restraint system design which would perform well in the scheduled 35 and 40 mph crash tests described in the foregoing. In these tests however, only the 50th percentile adult male ATD size was used in testing the driver and passenger systems. In the Phase II study however, additional program objectives were added to extend the scope of the total program. These added objectives included:

1. Use the test data derived in the Phase I study to further validate the DRACR and PAC computer models for the DeLorean vehicle's crash environment using using program input parameters that describe the preliminary restraint systems used in these crash tests.

2. Use these validated computer programs to investigate other crash velocities, operating environments, design specifications, occupant sizes, occupant positions, and sensing and/or inflator staging scenarios. This part of the study was called a "parameter sensitivity analysis".

3. Recommend design options and hardware component selection for a total restraint system package that, based upon the systems analysis, computer approach promises to most optimally meet the combined and sometimes conflicting requirements of the various occupant sizes, occupant positions and crash conditions applicable to the small vehicle.

The report written at the conclusion of Phase II contains

the results of the validation and sensitivity analyses presented in graphical form for ease of interpretation. Although these results are not the subject of this report, we urge interested readers who desire a more in depth understanding on the role of computer techniques in restraint system design and the effect various restraint system parameters and hardware components play in affecting injury levels, to consult this report.[1]

At the conclusion of Phase II we had the information necessary to make an intelligent selection of the components to be used in the Phase III sled testing. In the following section of this report we will describe the objectives of this Phase III program and the restraint systems design which evolved through the first two phases of the total program.

---

[1] "A Systems Analysis Approach to Integrating Restraint Systems into a Production Ready Small Car", Fitzpatrick Engineering, Final Report, Contract No. DTNH22-81-C-07557, Feb. 1982.

2.0 INTRODUCTION

In the foregoing discussion we have attempted to give an overview of the first two phases of the total program so that the results of the third phase, which is the subject of this report, may be seen in the total program context and, therefore, more readily understood.

In this section of the report we will, first, lay out the objectives of this phase of the program and then, second, discuss the hardware that comprises the driver and passenger airbag restraint systems as it existed just prior to entering the Phase III sled tests.

2.1 Program Objectives and Tasks

1. Drawing on the Phase I and Phase II results, specify the driver and passenger restraint system components to be procured for the Phase III sled tests.

2. Assist NHTSA's Vehicle Research and Test Center in East Liberty, Ohio in integrating and installing the driver and passenger restraint systems in the sled test buck.

3. Perform as Engineering Test Director for twelve sled tests to be conducted by the Transportation Research Center (TRC) in East Liberty, Ohio.

4. Using the Pase III sled test results and the Phase II computer simulations as a basis for judgement, determine whether the driver and passenger restraint systems

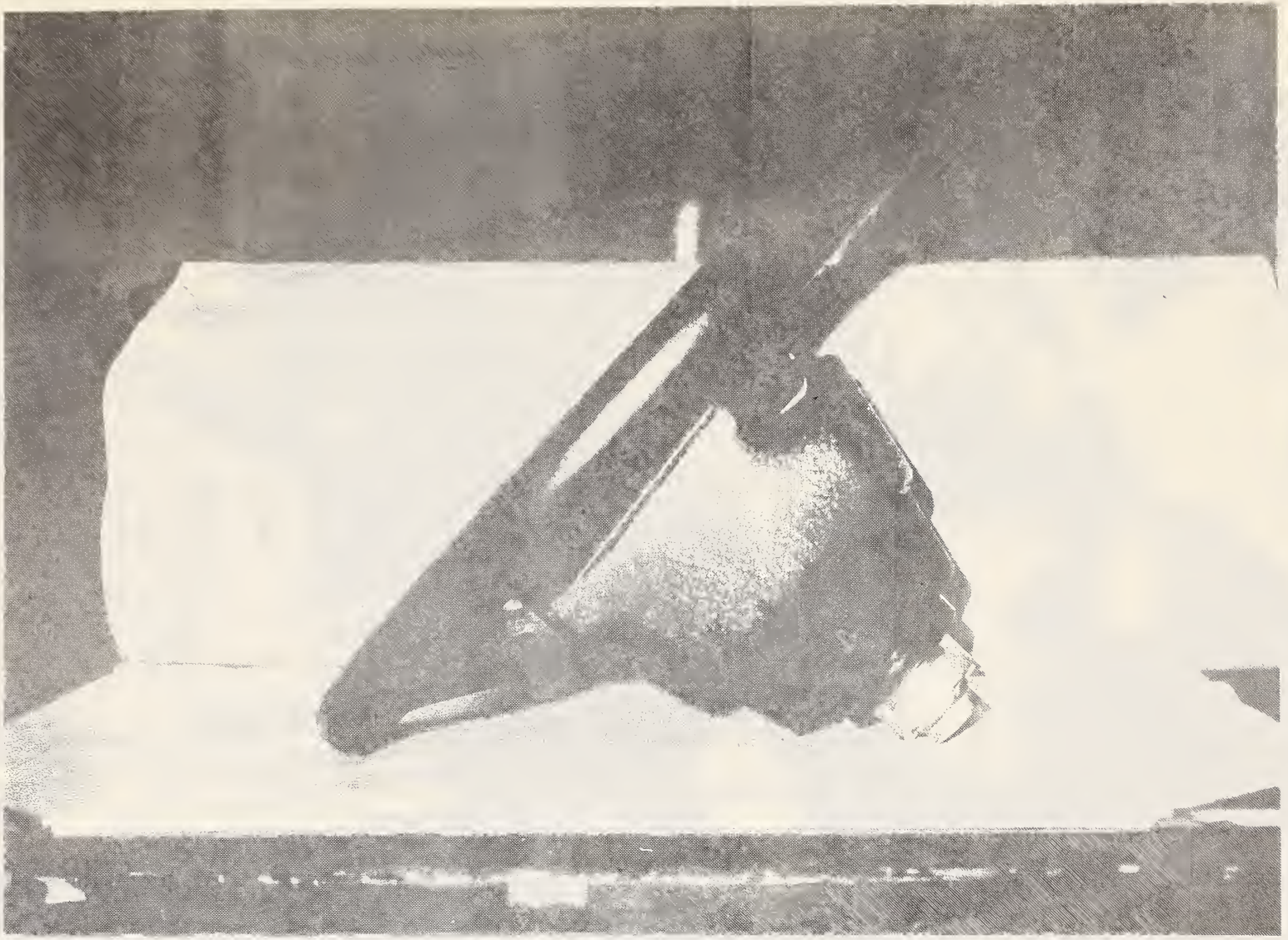
derived in this program perform as predicted thereby establishing the validity of this systems analysis approach for future work.

5. Using the Phase III sled tests results as a controlled test environment for comparison purposes, further validate the PAC and DRACR computer models' ability to predict injury severity when given specific crash and restraint system parameters as input data.

2.2 Restraint System Description

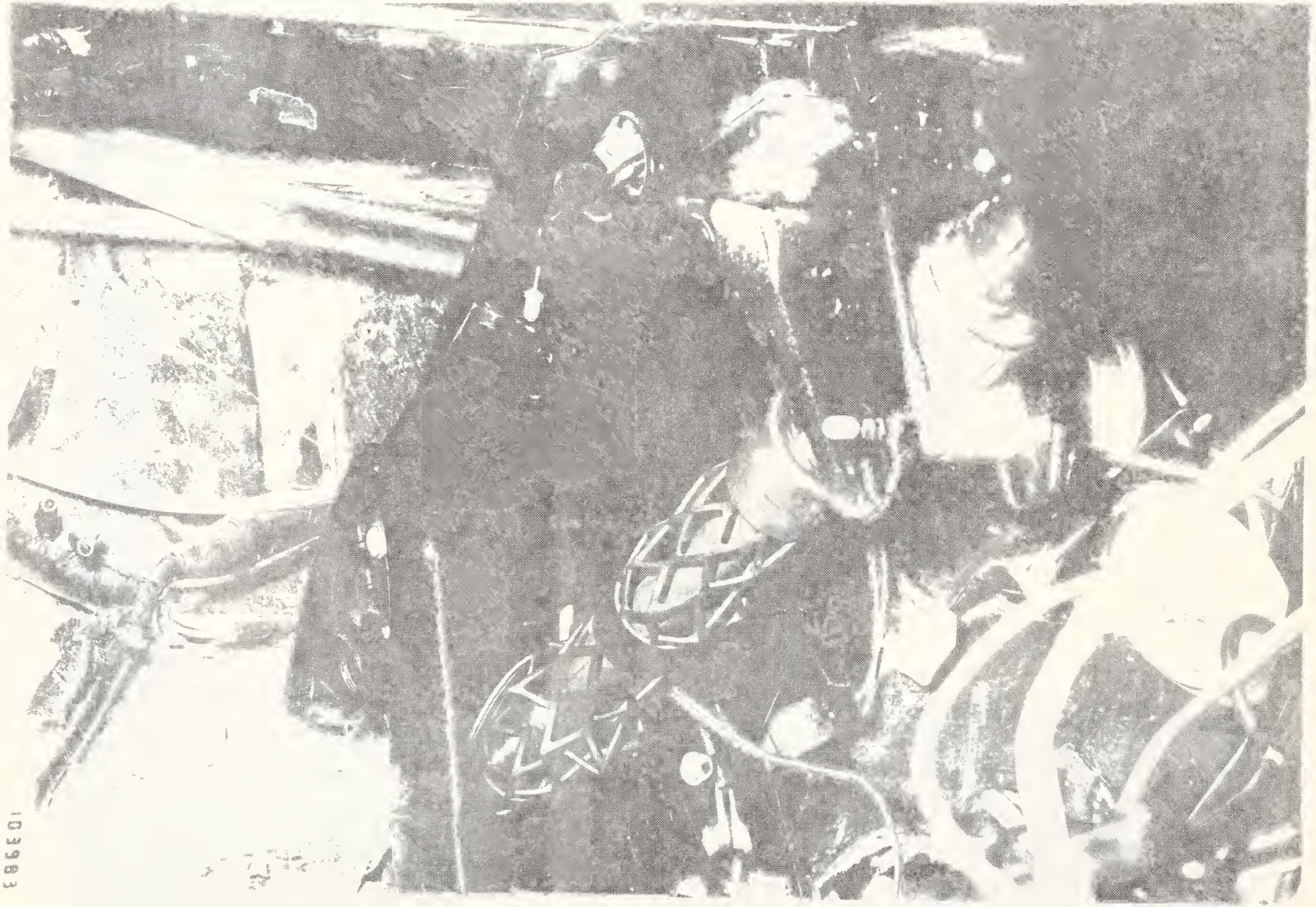
Driver

Component	Type Selected	Basis for Selection
Steering Wheel	1979 Volvo GT (Figure 2-1)	Production DeLorean wheel does not have volume available for inflator and airbag installation. Volvo wheel does and is also designed to deform during crash.
Steering Column	Unmodified DeLorean (Figure 2-2)	Test Series begun with unmodified DeLorean design; however during testing the tilt adjust was locked to prevent slippage.
Knee Restraint	Aluminum Honeycomb (Figure 2-3)	Dependable with known crush characteristics. Covered with soft, aluminum skin (another material with similar crush characteristics would also be satisfactory).



Volvo Steering Wheel

Figure 2-1



DeLorean Steering Column from Underneath

Figure 2-2.

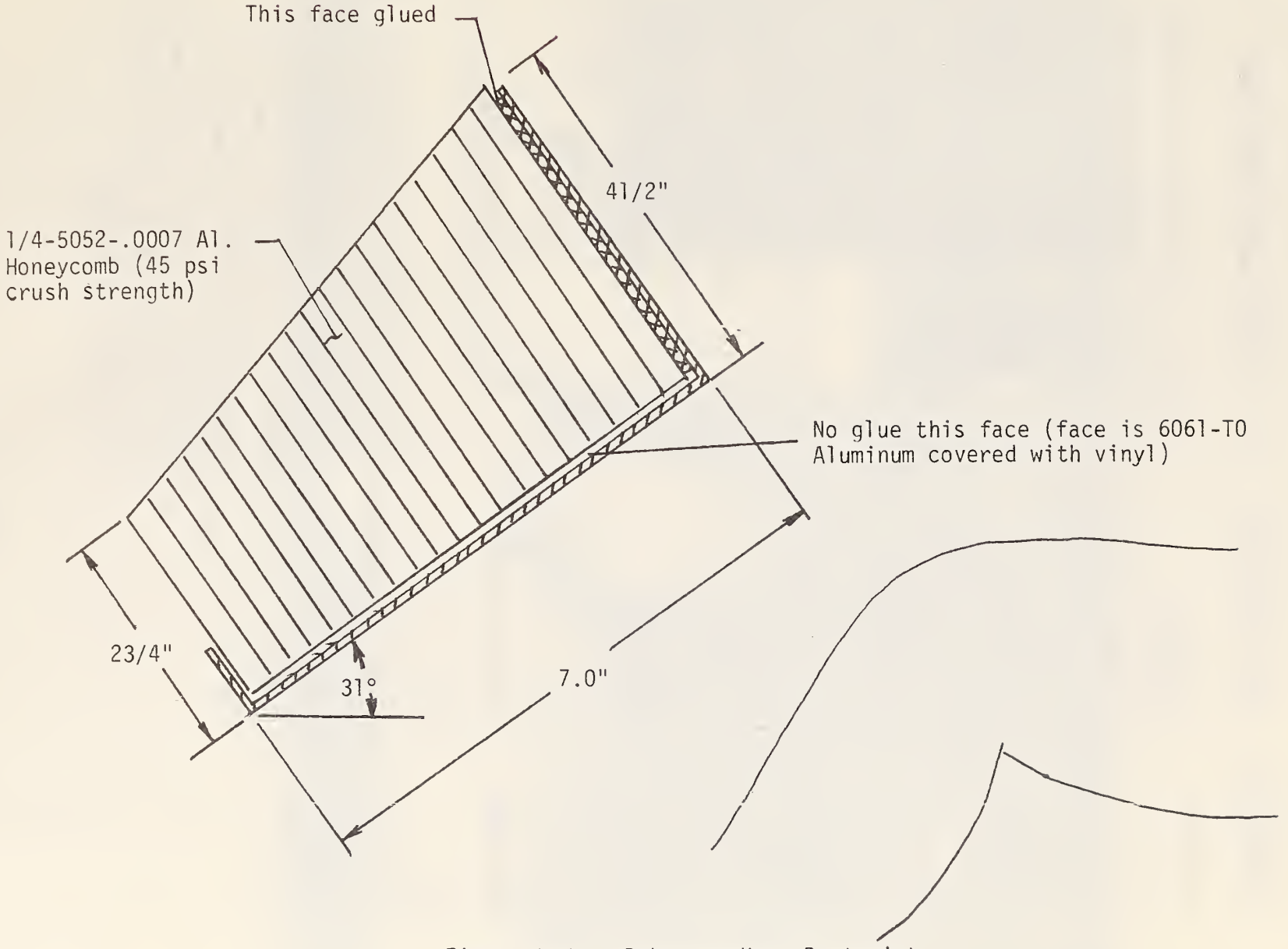
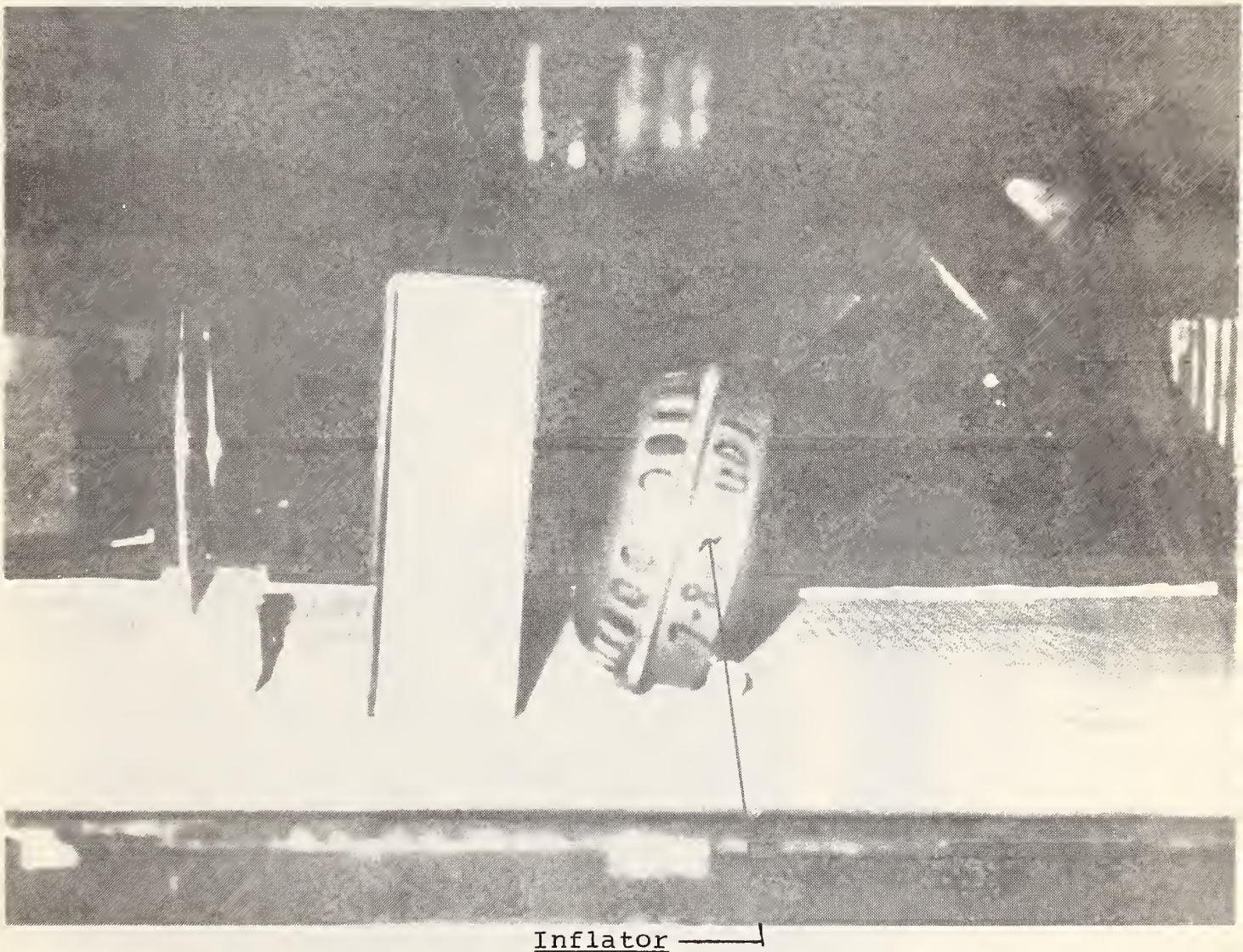


Figure 2-3. DeLorean Knee Restraint.

Component	Type Selected	Basis for Selection
Inflator	Thiokol/ Mercedes (Figure 2-4)	Computer Predictions indicated superior performance and production line is set up.
Airbag	Fitzpatrick Engineering design, Talley Manufactured (Figure 2-5)	Size, shape, volume and vent area determined by computer simulation. Drawings furnished to Talley for manufacture.
Packaging	Fitzpatrick Engineering design (Figs 2-6 - 2-9)	Past experience to design modules and support structure and to locate restraint system in sled test buck. (virtually identical with Phase I vehicle integration).

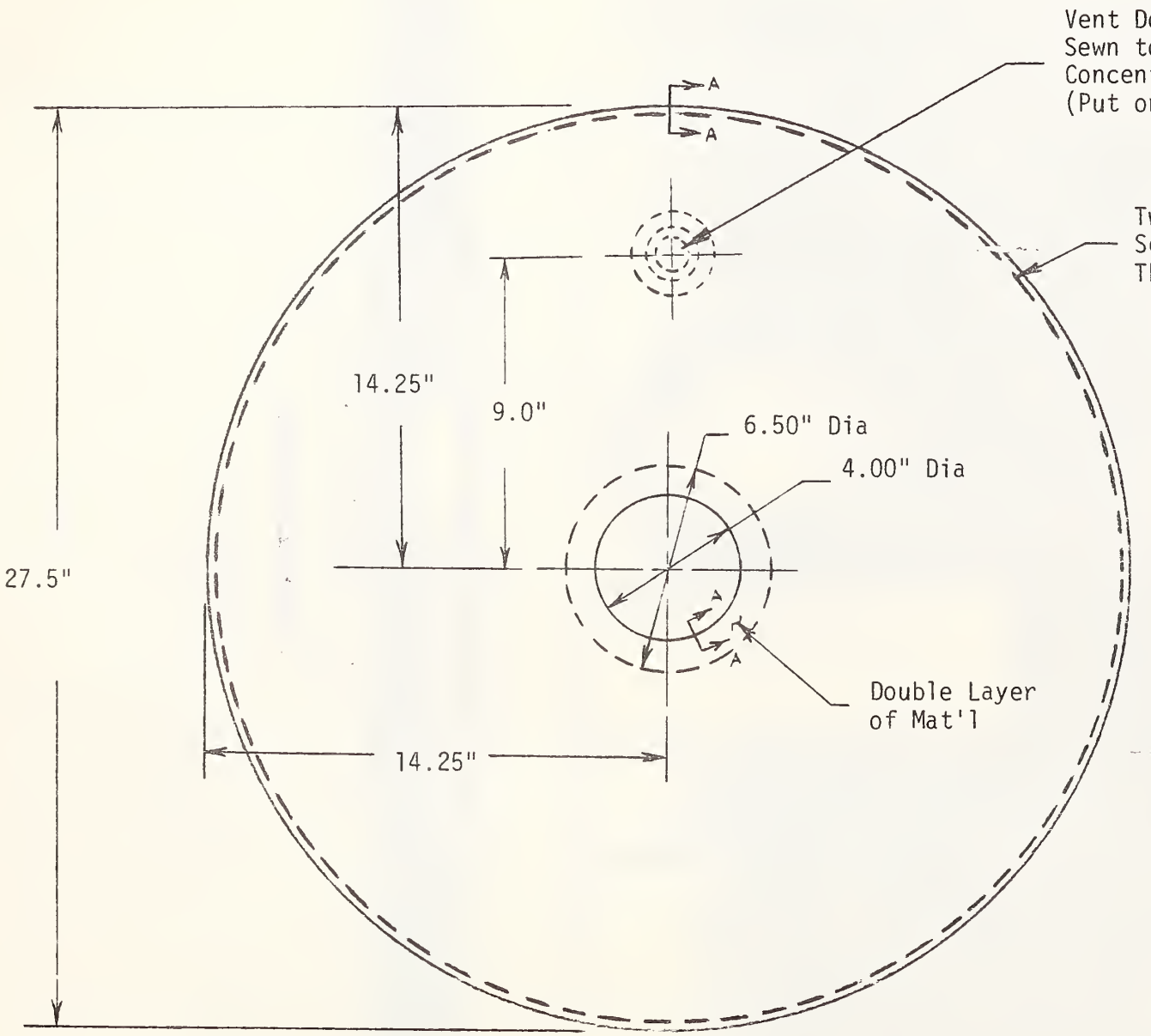
Passenger

Component	Type Selected	Basis for Selection
Knee Restraint	Same as driver	Same as Driver
Inflator	Thiokol/ Mercedes (Figure 2-4)	Selected two inflators identical with driver inflator based upon computer predicted superior performance for a range of passenger sizes and positions plus commonality with driver inflator.



Thiokol/Mercedes

Figure 2-4.



Mat'l Specs:

- Neoprene Coated Nylon
- Coated Wgt: 8.2 oz/yd^2
- Uncoated Wgt: 5.5 oz/yd^2
- Nylon, Type 66, 840 Denier
- Count, Warp & Fill 24x24

Seams:

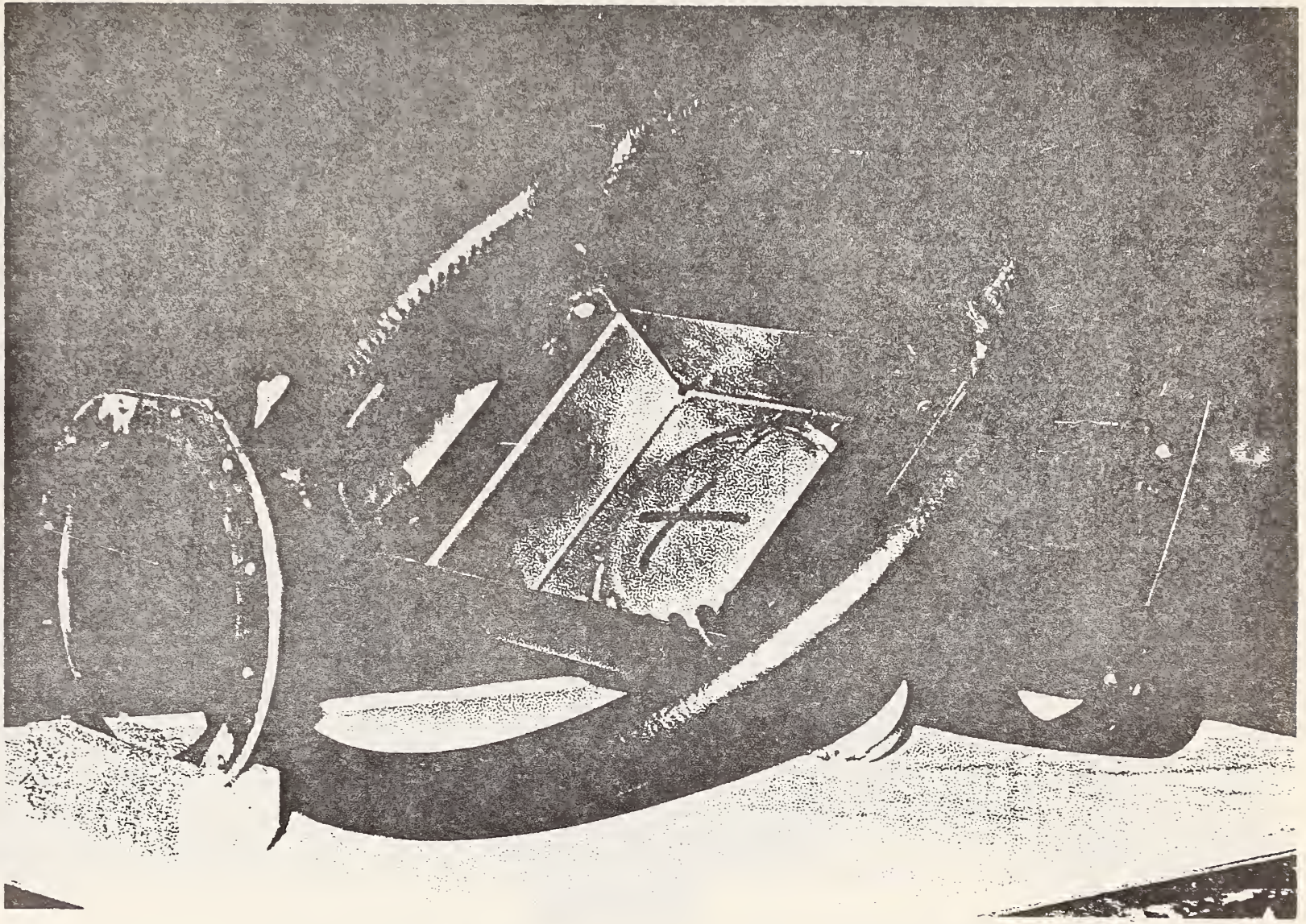
- Nylon Thread
- 10 Stitches/in
- 3 Rows Ea. Seam, Close Together

Vent Geometry:

Diameter: 1.63 in.

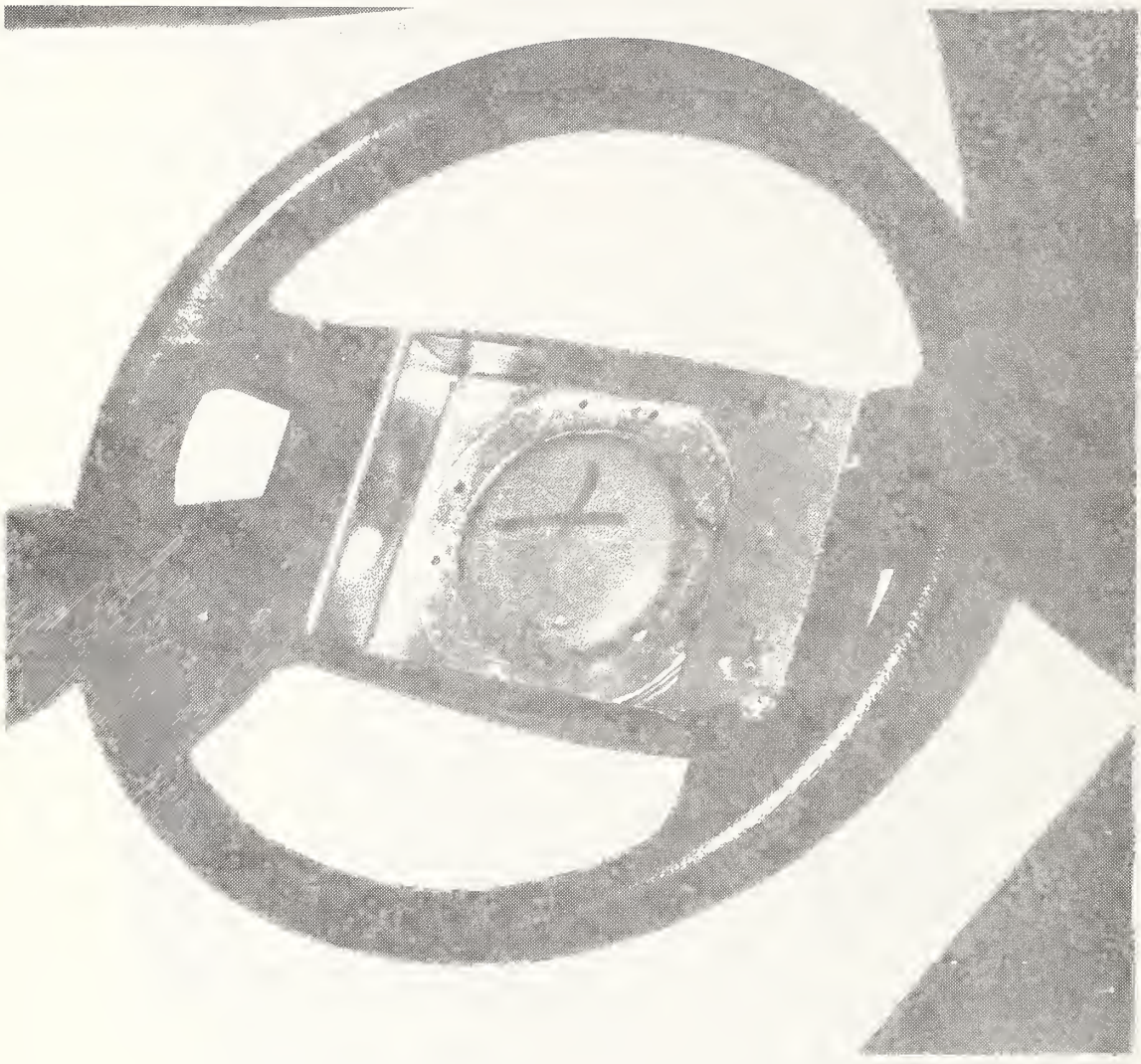
NOTE: DIMENSIONS SHOWN ARE FINISHED DIMENSIONS

Figure 2-5. Driver ACRS Bag Design.



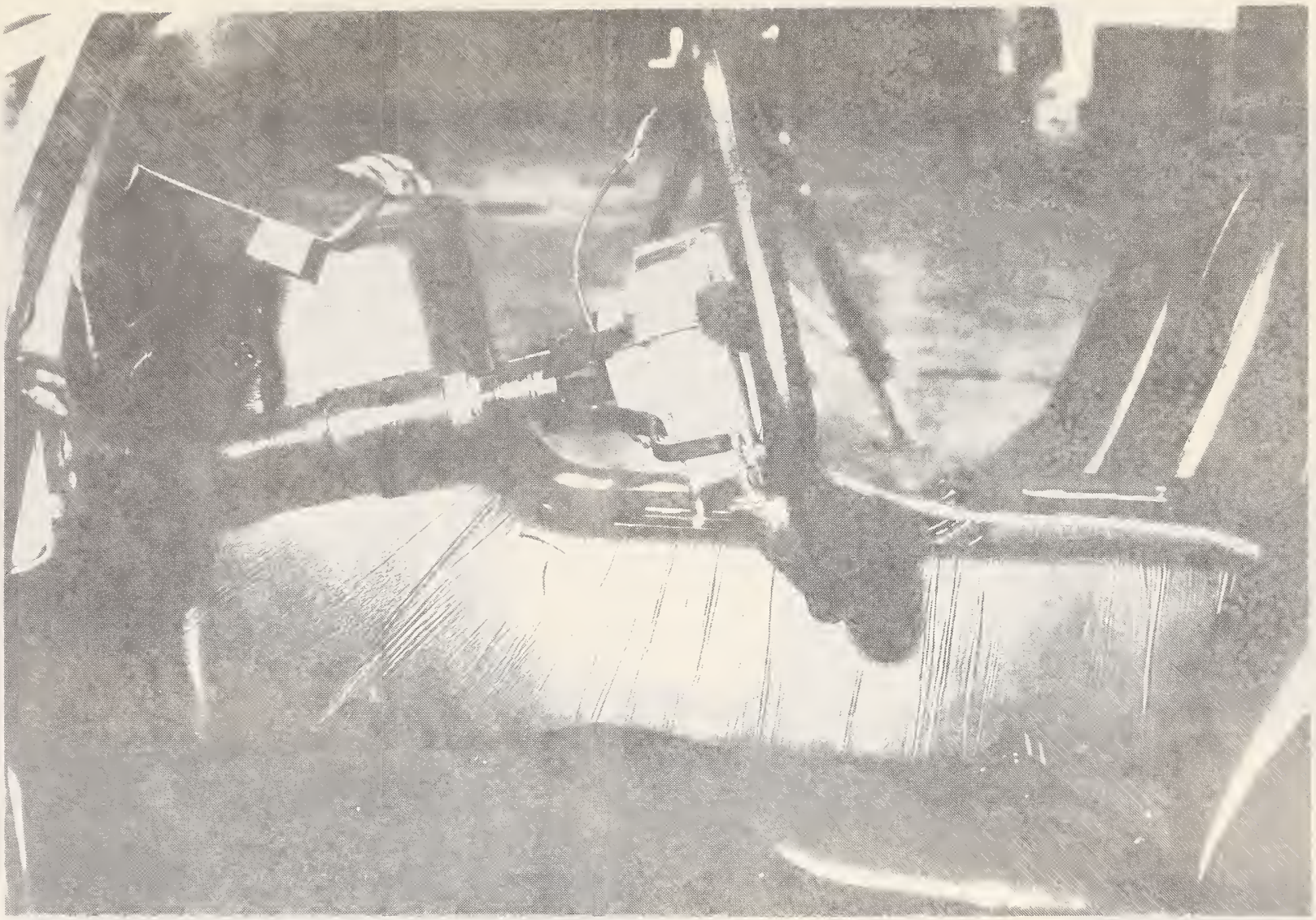
Driver Module Components

Figure 2-6.



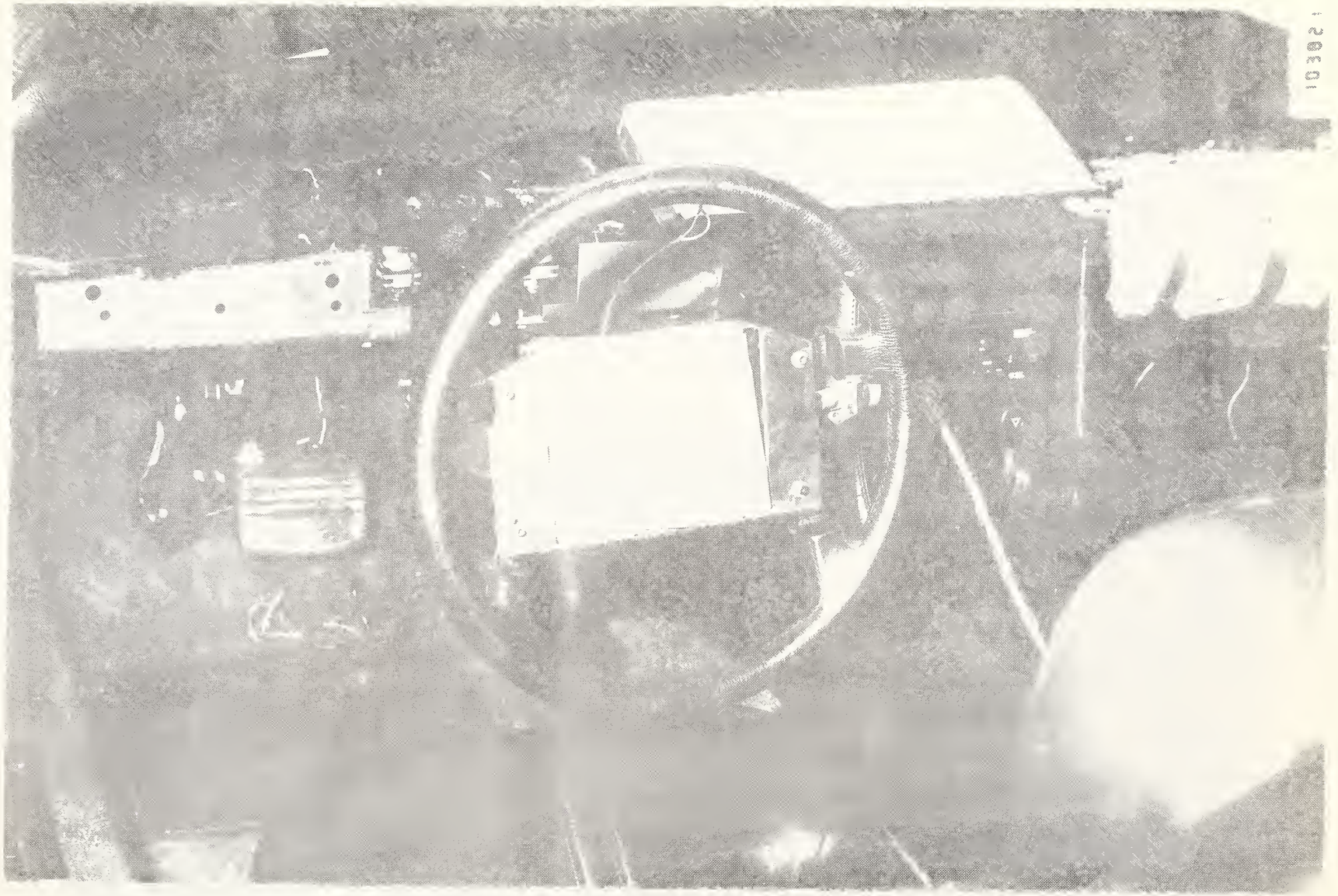
Inflator Installed in Driver Module

Figure 2-7.



Driver Module Installation (shown w/o housings)

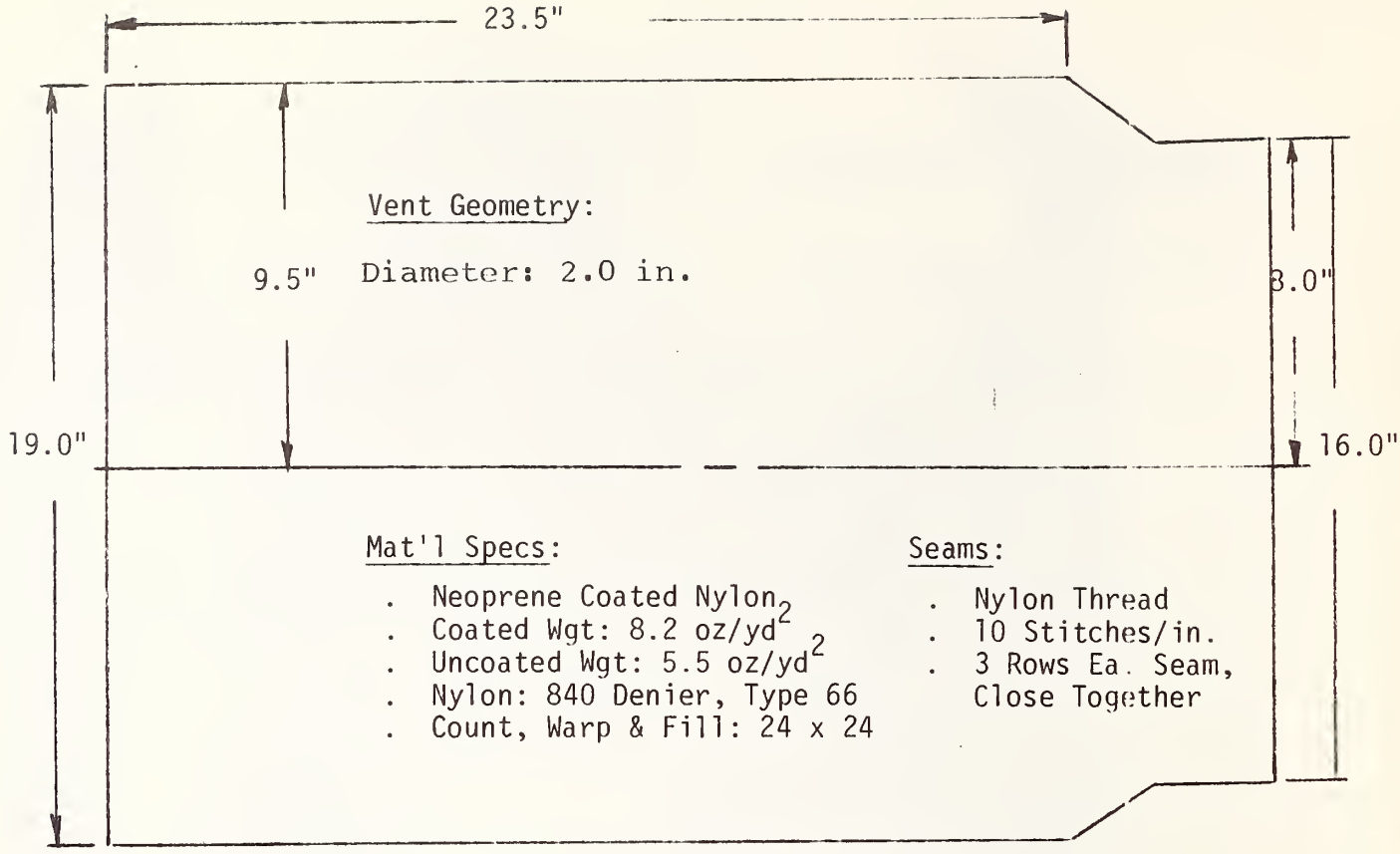
Figure 2-8.



Driver Module Installation (shown w/o housings and cowl)

Figure 2-9.

Component	Type Selected	Basis for Selection
Airbag	Fitzpatrick Engineering design, Talley manufactured (Figure 2-10)	Size, shape, volume and vent area determined by computer simulation. Drawings furnished to Talley for manufacture.
Packaging	Fitzpatrick Engineering design (Figs. 2-11 to 2-14)	Past experience used to design housings, adaptors, modules, and support structure for installation in sled test buck.



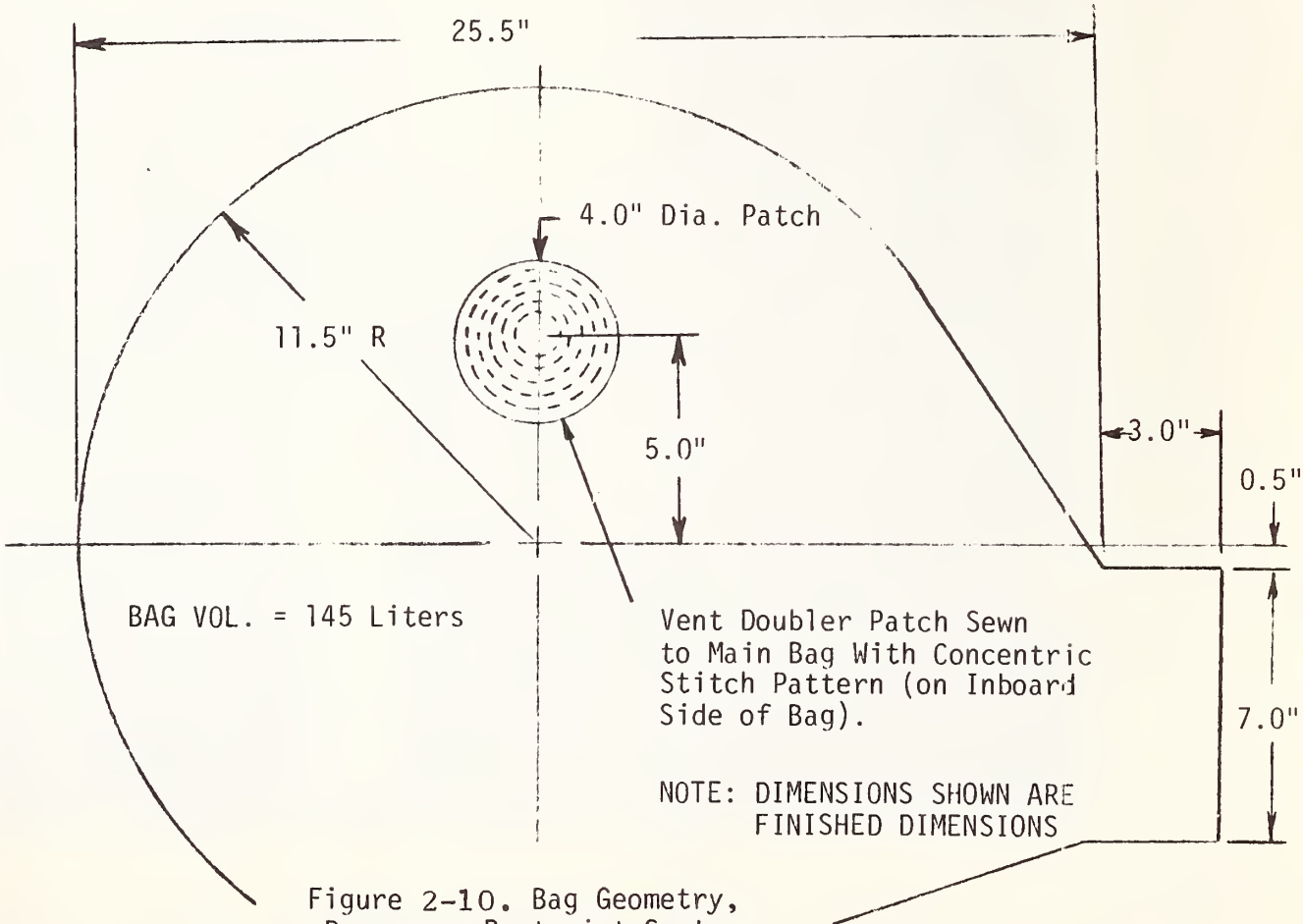
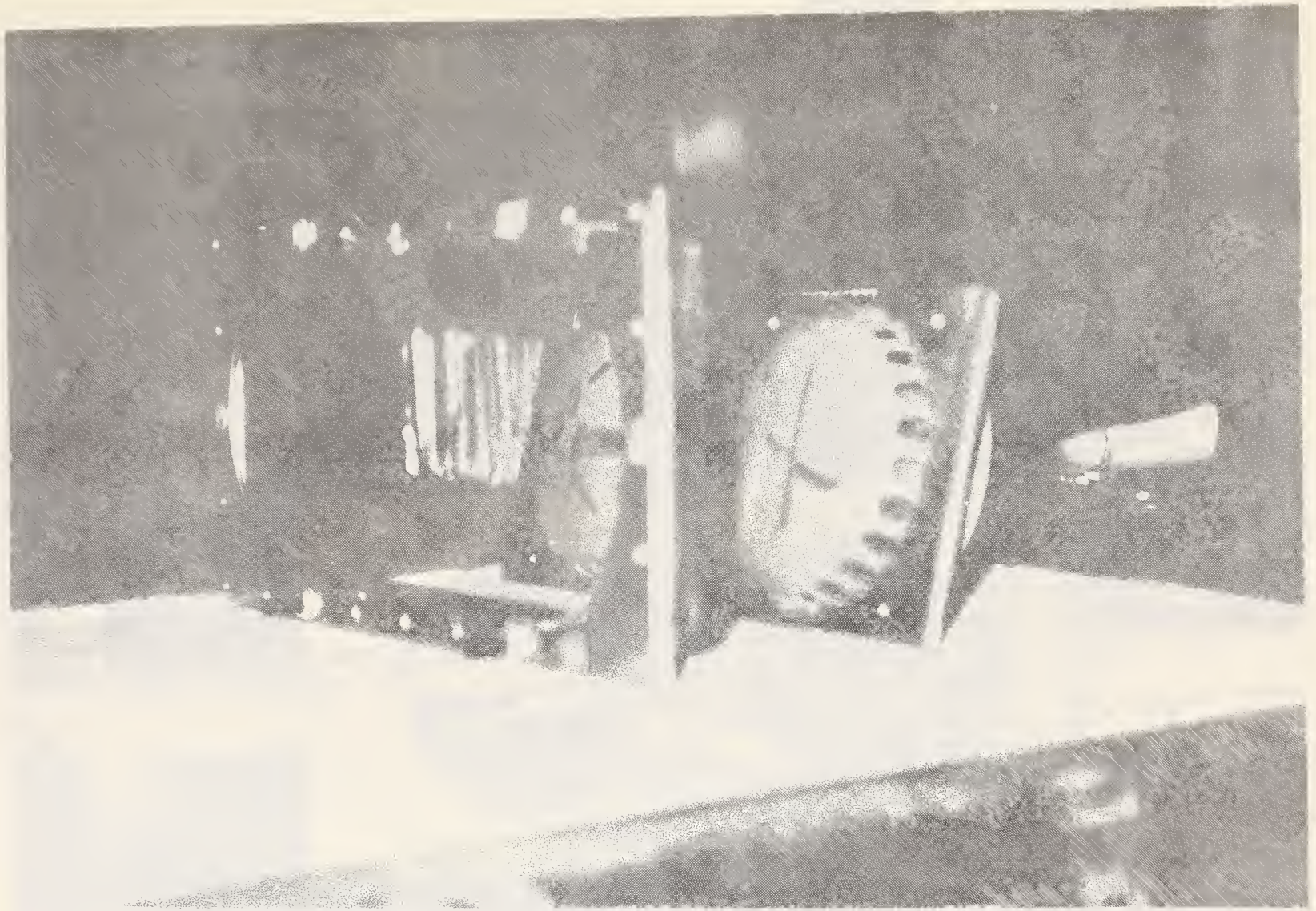
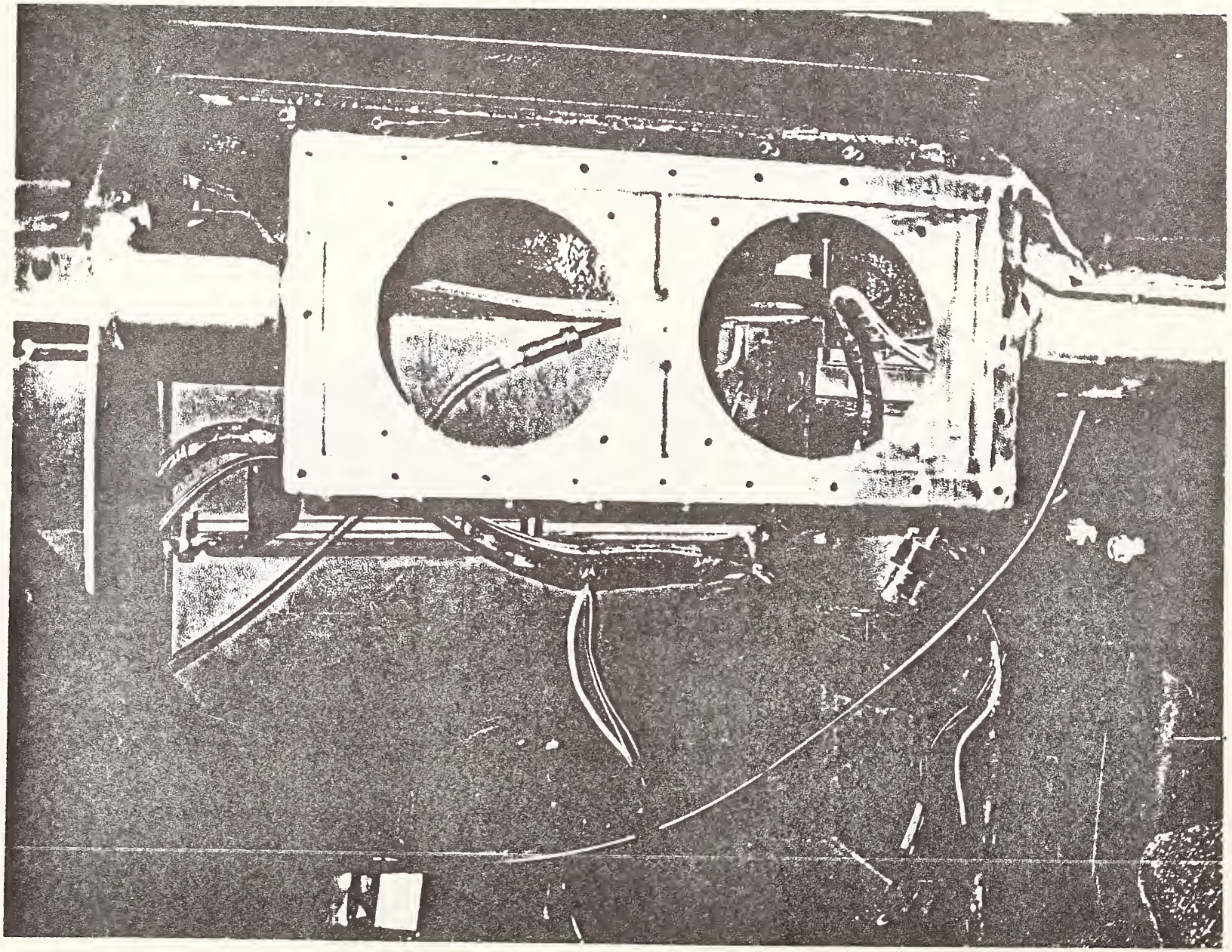


Figure 2-10. Bag Geometry, Passenger Restraint System.



Passenger Module Components (minus airbag)

Figure 2-11



Passenger Module Inflator Mount

Figure 2-12.

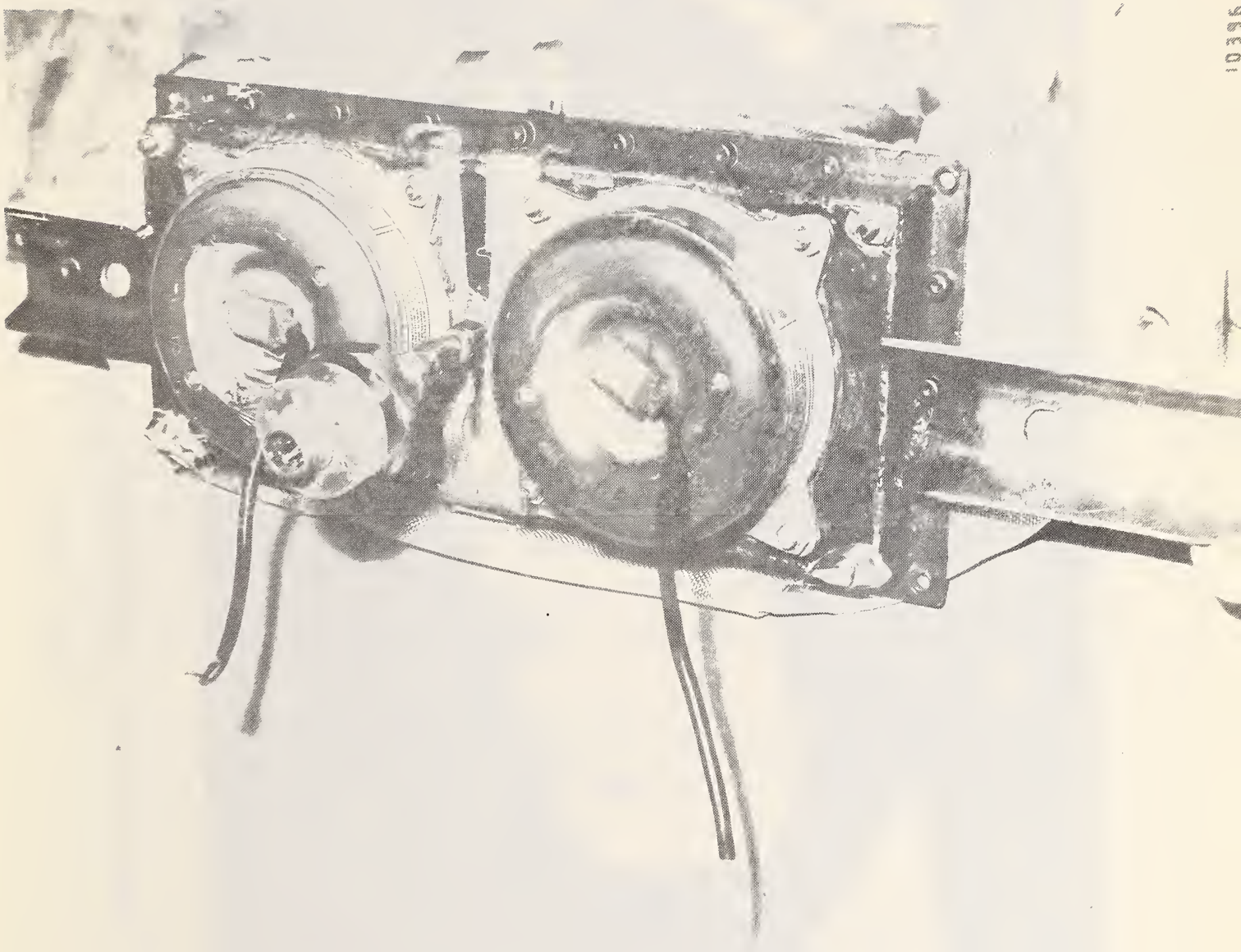
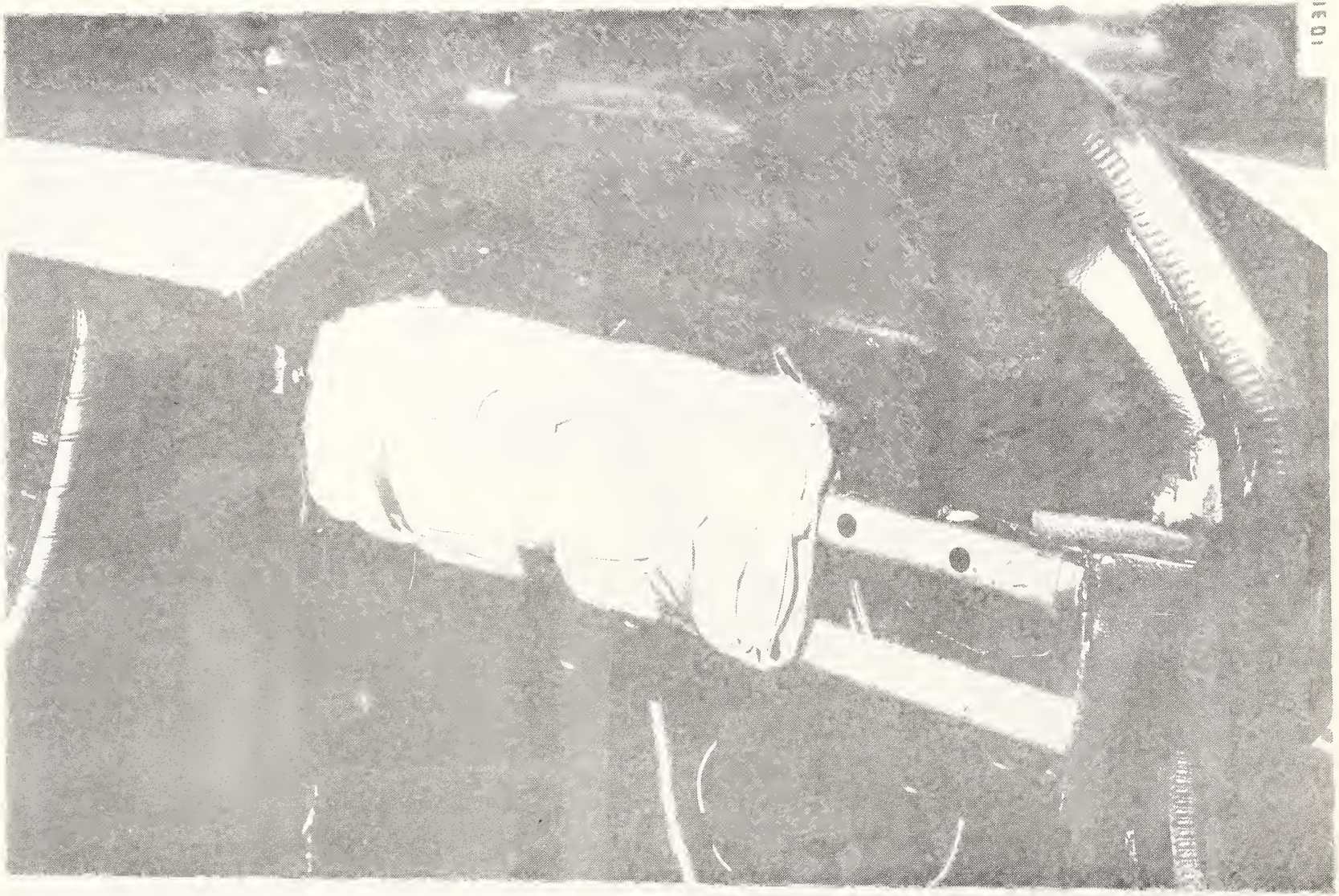


Figure 2-13. Inflator and Module Pan



Passenger Airbag System (shown w/o covers)

Figure 2-14.

3.0 SLED TEST PREPARATIONS

With the preceding description of the restraint systems given as background, let us now discuss the details of:

1. Fabrication of the sled test buck and the restraint systems installation into the test buck.

2. Selection of the sled test crash pulse that most nearly matches the crash test pulse.

3.1 Sled Buck Fabrication and Restraint Systems Integration

During the time spent awaiting the shipment of the hardware components described in the preceding section, the Vehicle Research and Test Center with Fitzpatrick Engineering assistance took a vehicle body furnished by the DeLorean Motor Company and made the modifications and reinforcements necessary to withstand the repeated rigors of sled testing.

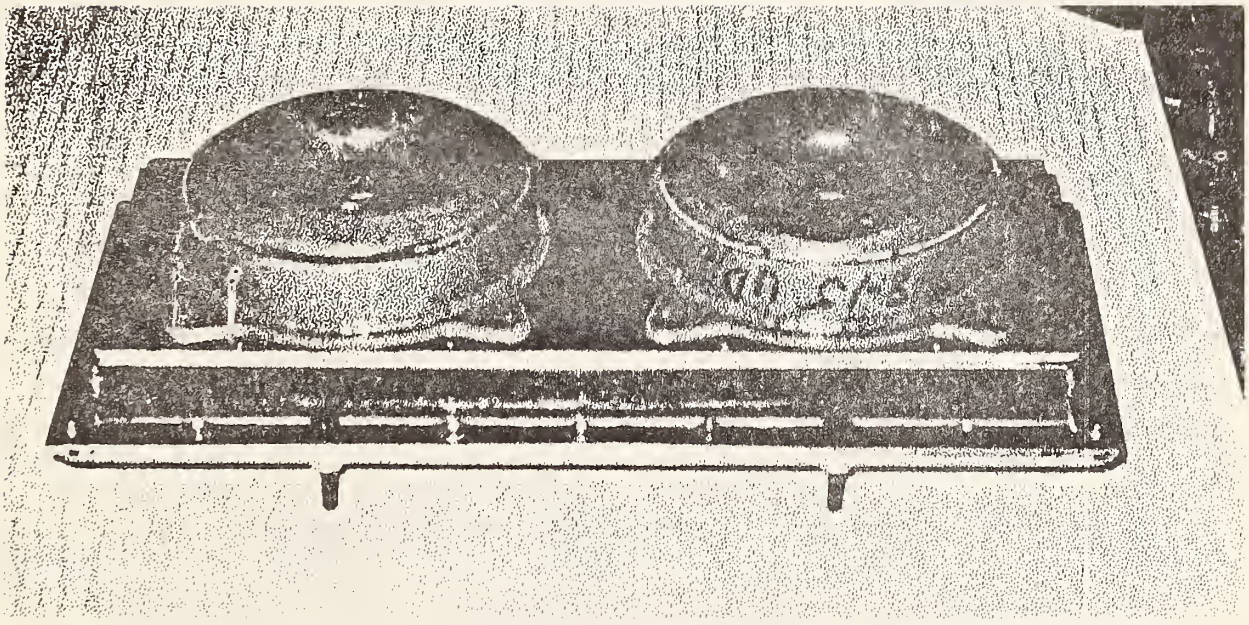
Once the restraint system hardware had arrived at the test site, VRTC, with direction provided by Fitzpatrick Engineering, began the integration of the restraint system components into the test buck.

During the integration effort our objectives were to effect the integration in a cost effective manner typical of what, if not how, might be done in production. That is, we attempted to use prototype shop techniques to fabricate structure which would approximate the configuration in which the various restraint system components might be mounted in production.

Very briefly, the configuration used was to bolt 12 gage sheet metal to the fiberglass A-Posts and center X-frame "spine" to provide mounting surfaces for the knee restraints and the passenger airbag module. By using this attachment configuration and the relatively small module design shown in Figure 3-1, it was possible to effect this integration without infringing on the space occupied by the air conditioning or glove box.

3.2 Sled Pulse Selection

One of the crucial choices in any sled test program in which a particular crash environment is being duplicated is to make an intelligent choice of the corresponding sled test pulse. Obviously, since the actual vehicle structure and its corresponding deformation patterns are not duplicated in a sled test, it is only possible in a sled test to approximate the vehicle crash pulse. The question then becomes, which crash profile of the many that may be duplicated on the sled will most nearly simulate the injury measures which were actually recorded in the crash? Naturally, if one were able to "exactly" duplicate the crash pulse on the sled, we would do so; however in actuality the sled pulse cannot be made to do this and so a means of determining which sled pulse is "close enough" becomes necessary. Since we had just completed the Phase II computer simulations of the driver and passenger interacting with their respective restraint systems and had obtained a good match between computer results and the actual crash, we had a unique opportunity to answer this question in the only really meaningful way. This way was to select the crash pulse for the sled tests according to the criteria of "equivalent injury". The method was as follows:



Inflator Installed in Passenger Module

Figure 3-1.

Using the "PAC" (Passenger Air Cushion) computer model with the input paramters that gave the good match between simulation and the 36 mph crash test and changing only the crash pulse input to that available for the DeLorean buck at TRC, select the metering pin and associated "set pressures" that, based upon computer simulation, yields "equivlaent injury" to the passenger.

Fitzpatrick Engineering and TRC evaluated the available sled pulses in two preliminary ways. First, a "catalogue" of past sled runs was investigated to select a few candiate pulses for preliminary consideration. Second, a few sled runs were made with the DeLorean buck using the metering pins and set pressures that looked most promising. Table 3-1 best summarizes the results of this comparison by showing the injury measures that:

1. actually were measured in the 36 mph crash test.

2. obtained in a computer simulation of this same test.

3. obtained in computer simulations in which only the crash pulse part of the input was changed to match the sled test pulse.

Figures 3-2 through 3-5 show the actual crash pulses used in these simulations. In all cases they faithfully represent the actual crash pulses.

Table 3-1

Injury Measures

Right Front Passenger - 50th Percentile Male

	DeLorean Crash Test 36 mph	Comp. Sim. Crash Test 36 mph	Comp. Sim. Selected Sled Pulse	Comp. Sim. Rejected Sled Pulse
HIC	371	436	444	735
Pk Res. Chest G's (-3 msec)	42.5	40.5	41.2	49.0
Pk Femur Load - Lb	1220	1200	1200	1200

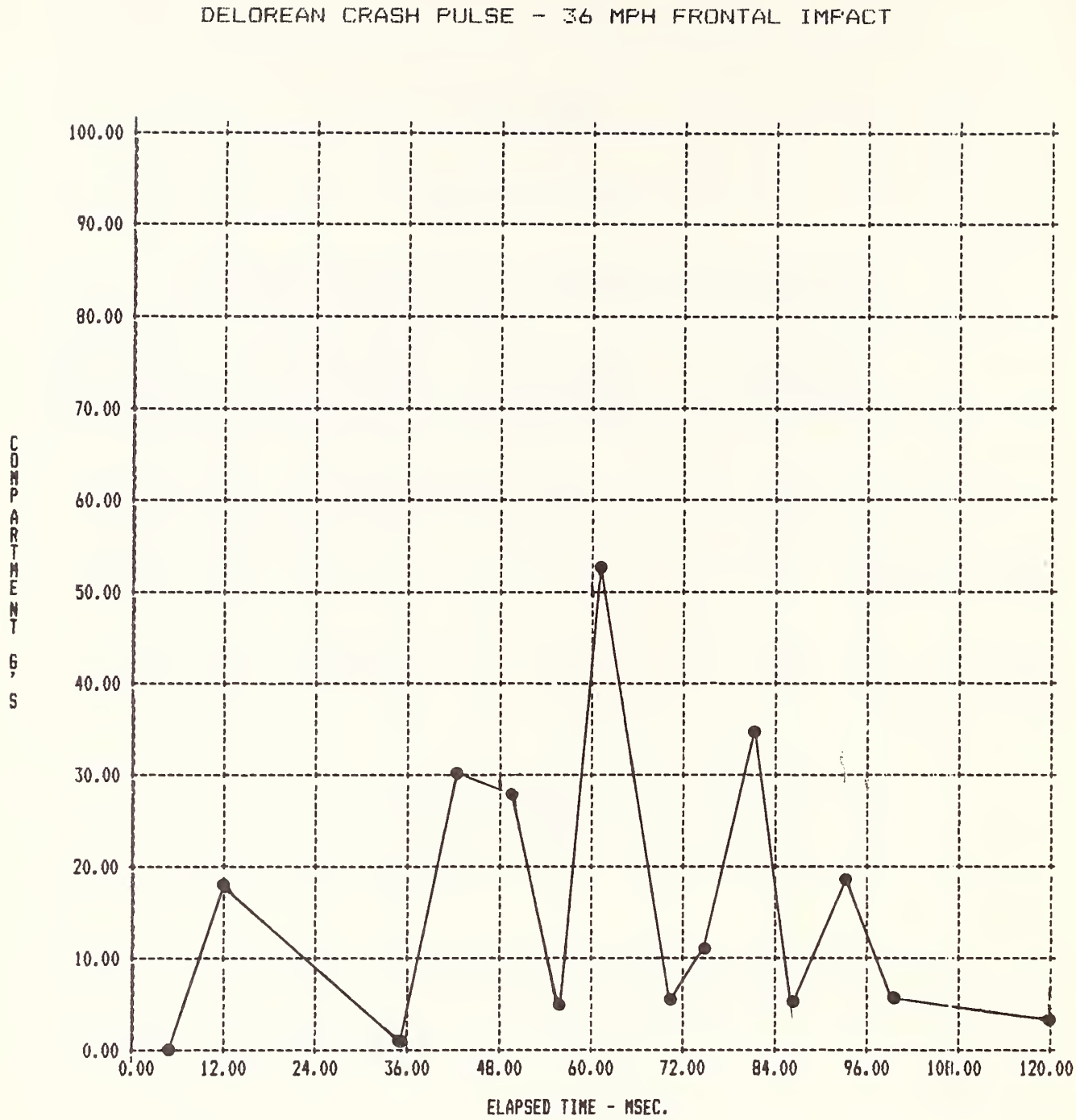

DELOREAN CRASH PULSE - 36 MPH FRONTAL IMPACT
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
COMPARTMENT G'S
0.00
12.00
24.00
36.00
48.00
60.00
72.00
84.00
96.00
108.00
120.00
ELAPSED TIME - MSEC.

Figure 3-2.

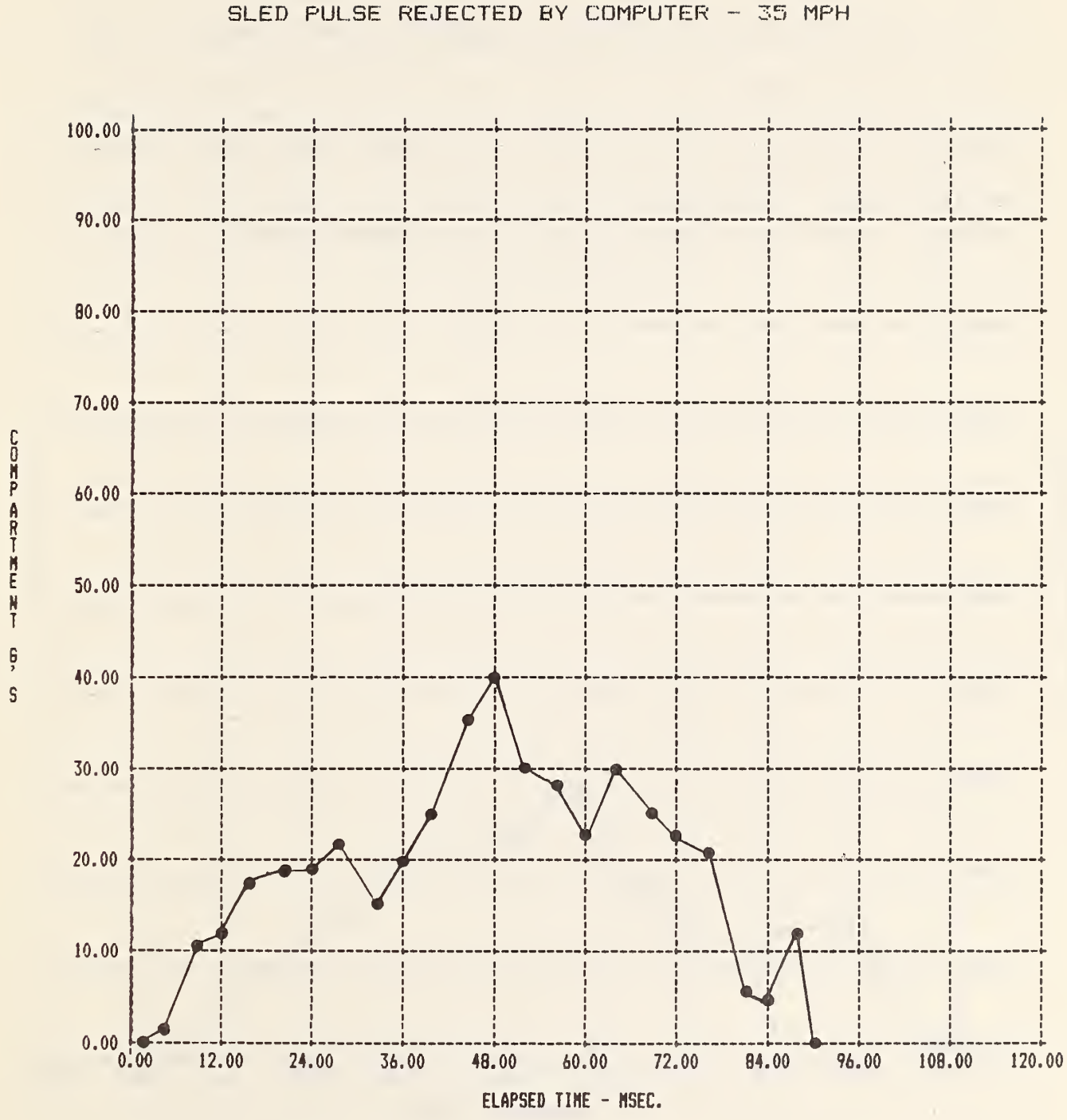

SLED PULSE REJECTED BY COMPUTER - 35 MPH
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
COMPARTMENT G'S
0.00
12.00
24.00
36.00
48.00
60.00
72.00
84.00
96.00
108.00
120.00
ELAPSED TIME - MSEC.

Figure 3-3.

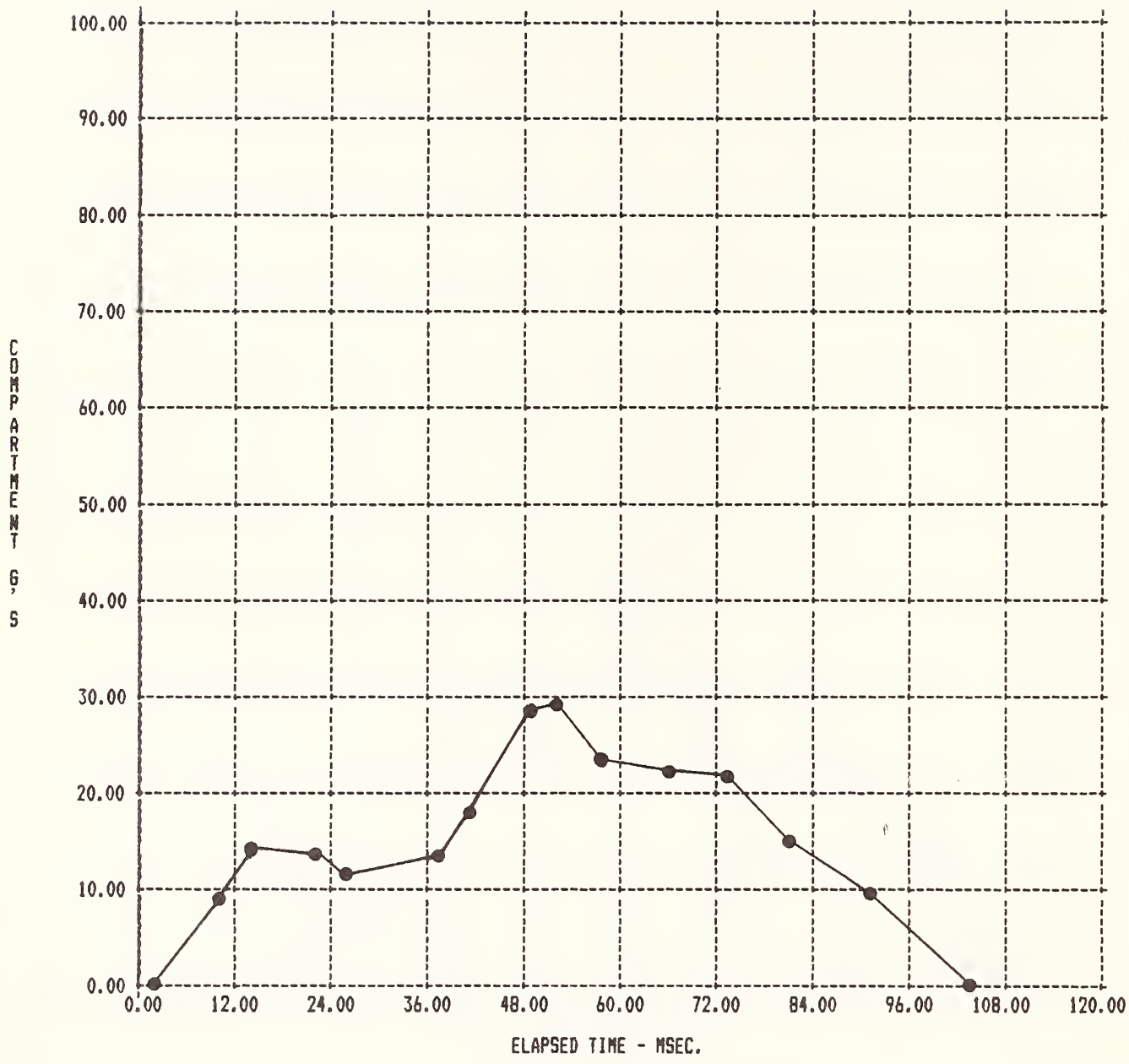

SLED PULSE SELECTED BY COMPUTER FOR 35 MPH
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
COMPARTMENT G'S
0.00
12.00
24.00
36.00
48.00
60.00
72.00
84.00
96.00
108.00
120.00
ELAPSED TIME - MSEC.

Figure 3-4.

Figure 3-2 shows the actual 36 mph crash test pulse as input into the computer. Figure 3-3 is a potential sled test pulse which was rejected as too severe by virtue of the predicted injury measures which were considerably higher than in the crash for equivalent impact speed. Figure 3-4 shows the sled pulse actually selected for the 35 mph sled tests. As may be seen in Table 3-1, this sled pulse resulted in expected dummy injury measures which most nearly matched the crash test which was the basis for its selection.

4.0 SLED TEST RESULTS

Once the sled pulse had been selected and the sled buck and restraint systems readied for test, the sled test series was ready to begin at TRC. Twelve sled tests were scheduled for this series of tests.

4.1 Test Objectives

The objective of this phase of the total program was four-fold:

a) to further establish the validity of the systems analysis approach to restraint systems design through testing the computer derived systems under a wider variety of crash conditions than done in the two Phase I crash tests,

b) to determine whether the ACRS design which had evolved to this pre-test point needed further tuning,

c) to investigate the driver and passenger restraint systems' ability to protect the full range of occupant sizes in the specified crash environment,

d) to draw conclusions and make recommendations that relate to the systems analysis approach to restraint systems design in general and to the performance of the DeLorean system in particular.

4.2 Test Selection Methodology

There are really two primary ways of approaching a sled test program. The first way is to lay out a test matrix by deciding

before-hand the precise test sequence that will be followed. The second way is to decide in general fashion the types of tests that must be conducted to satisy the overall test objective and then start the testing with the conditions that appear least tractable - proceding to other modes as conditions warrant. It is this latter, more flexible mode we employed in this Phase III program.

Computer simulations conducted in Phase II indicated that the injury measures for the adult size range for both the driver and passenger at impact speeds up to and beyond 35 mph should be well below the criteria limits of HIC less than 1000, peak resultant chest g's less than 60, and femur loads less than 2250 lb (50^{th} percentile male). Figures 4-1 and 4-2 from the Phase II report are included here to demonstrate this point.[1] (Femur loads are not shown in these figares but were in all cases predicted to be less than 1200 lb.)

A further indication that the adult size range would receive very good protection from both the driver and passenger air cushion restraint systems were the comparatively low injury measures received by the 50^{th} percentile male ATD's in the 36 and 41 mph frontal crashes reported in the final report for the Phase I crash tests.[2]

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[1] "A Systems Analysis Approach to Integrating Restraint Systems into a Production Ready Small Car", Fitzpatrick Engineering, Final Report, Contract No. DTNH22-81-C-07557, Feb. 1982.

[2] "A Systems Analysis Approach to Integrating Restraint Systems into a Production Ready Small Car", Fitzpatrick Engineering, Final Report, Contract no. DTNH22-81-C-07330, Nov. 1981.

10 X 10 TO THE INCH 46 0702
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO

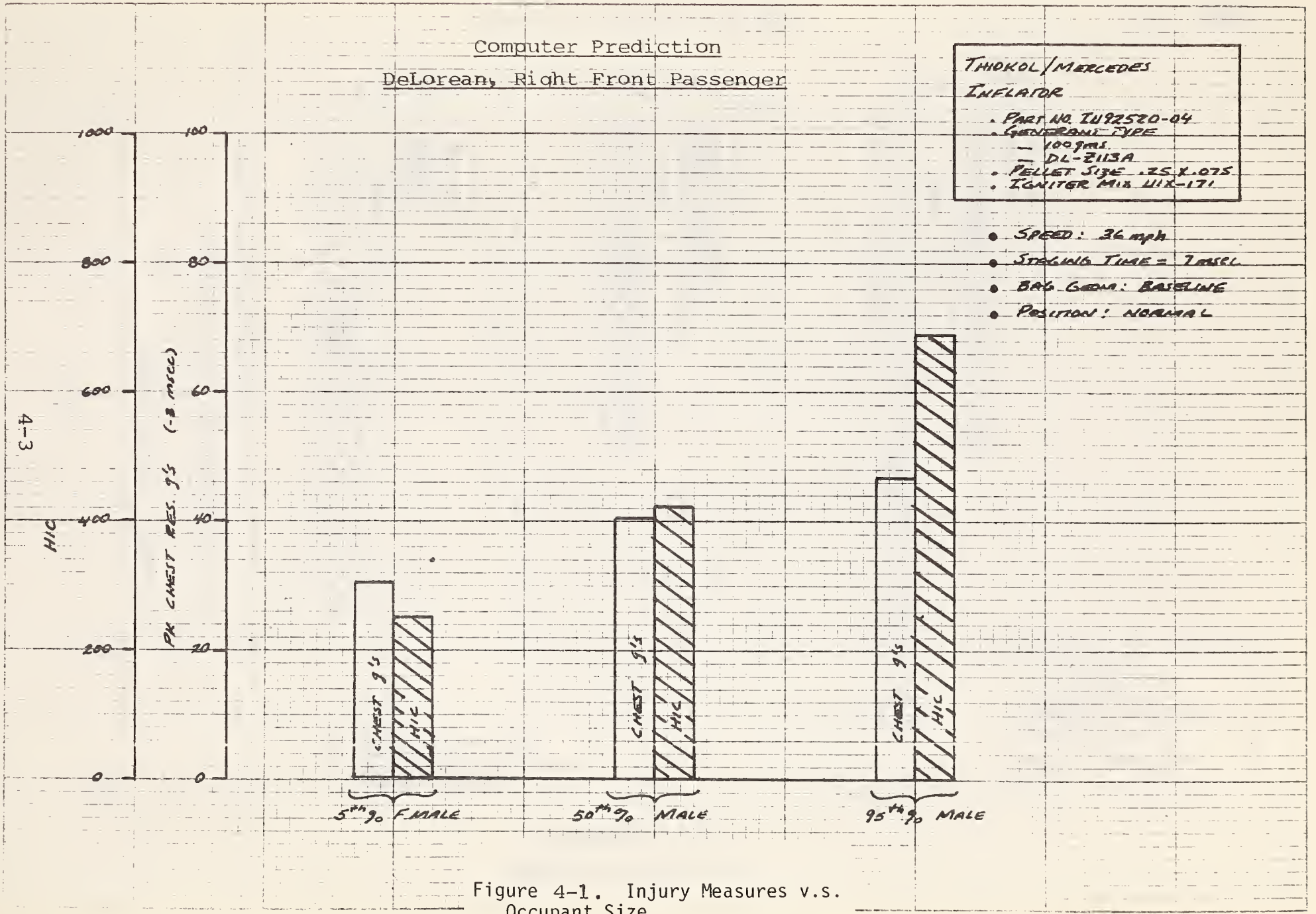

Figure 4-1. Injury Measures v.s. Occupant Size.

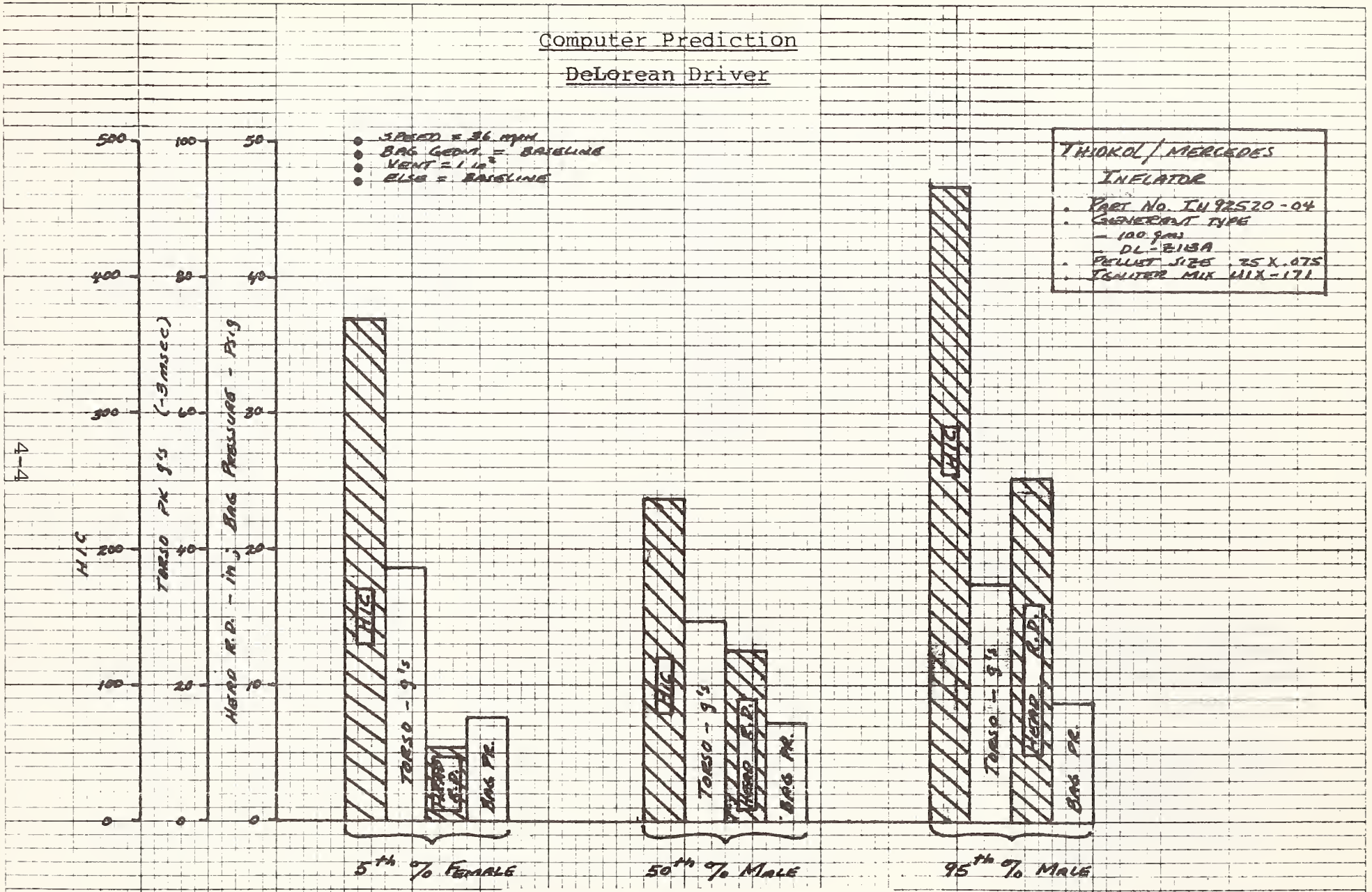

Figure 4-2. Effect of Occupant Size on Restraint System Permance.

The only potential problem indicated in the Phase II computer simulations for the adult driver or passenger was the prediction of impact of the 95th percentile head with the header and/or windshield in the "low slung" DeLorean compartment.[1] However it was decided to wait until the Phase III sled testing to see if this really would be a problem (this will be discussed in detail later).

There was, however, based upon the Phase II computer simulations, a theoretical position a small child could assume that, under certain crash conditions, could produce injury measures higher than the criteria limits.[1] This potentially critical condition for the small child (3 year old assumed in the simulation) was theoretically critical only for the case where the car was undergoing a frontal barrier crash at or in excess of 30 mph with the child seated approximately six inches from the stowed airbag. Other configurations for the child such as standing, further from the dash, normally seated or the static (vehicle not in a crash) cases were much less severe and not at all critical. Figures 4-3 through 4-6 show these conditions graphically. This data is taken from the Phase II computer simulation results.

The point we are making here is, since computer simulation indicated the forward positioned child undergoing a crash at or in excess of 30 mph to be the most critical design condition and since we already had two successful crash tests

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[1] Ibid., page 4-2, Section 4.0

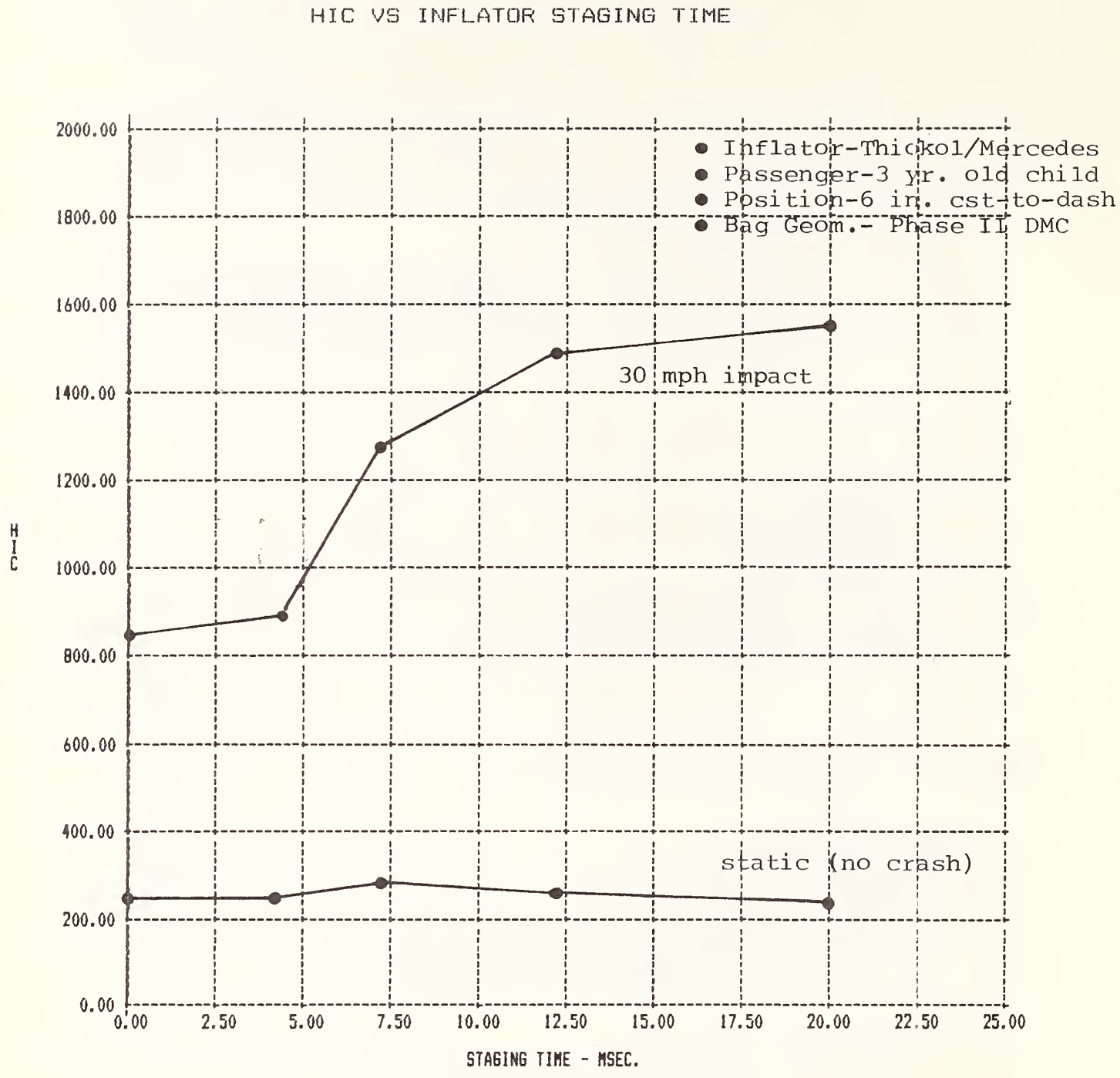

HIC VS INFLATOR STAGING TIME
Inflator-Thiokol/Mercedes
Passenger-3 yr. old child
Position-6 in. cst-to-dash
Bag Geom.- Phase II DMC
30 mph impact
static (no crash)
HIC
2000.00
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
0.00
2.50
5.00
7.50
10.00
12.50
15.00
17.50
20.00
22.50
25.00
STAGING TIME - MSEC.

Figure 4-3

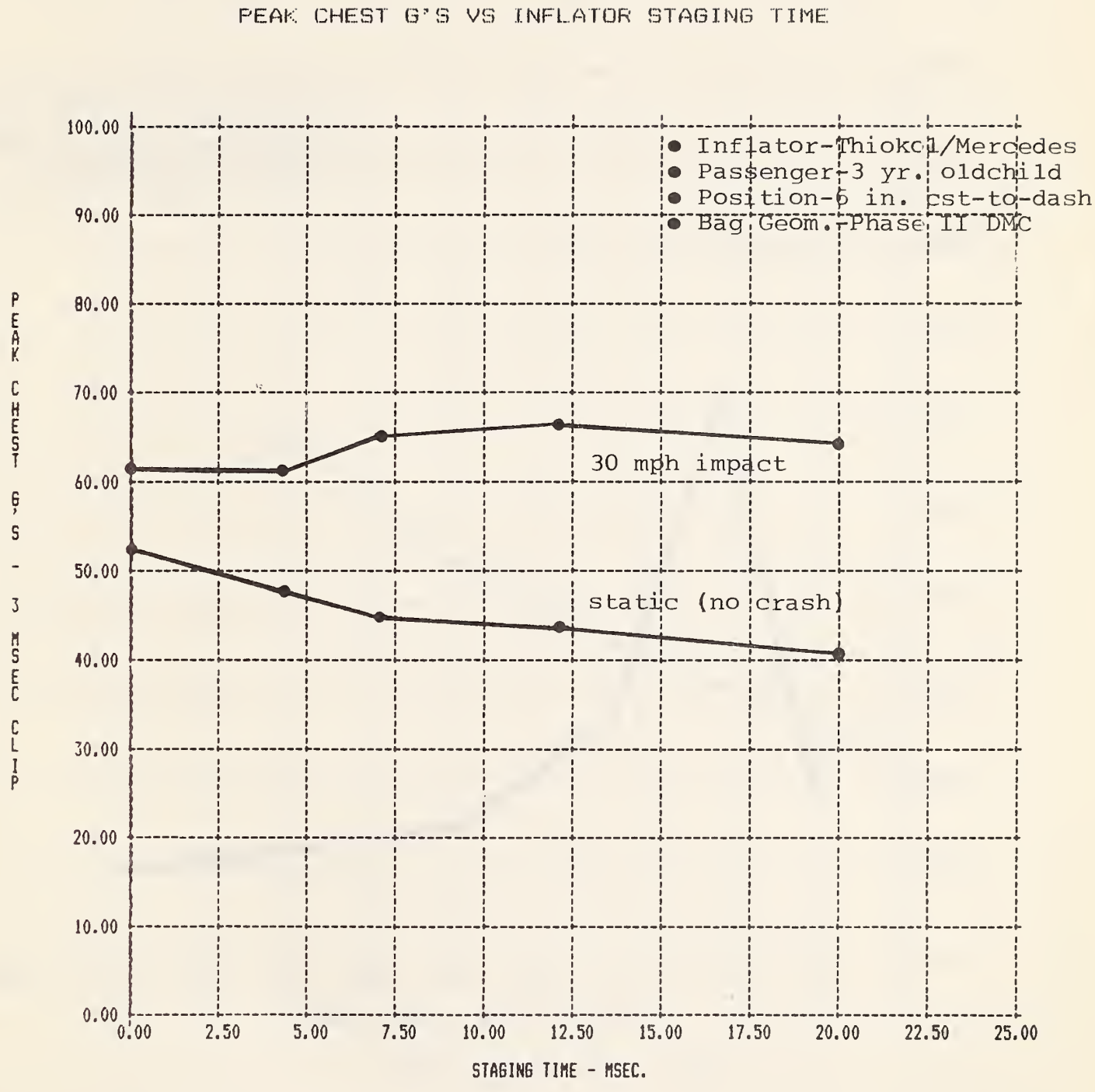

PEAK CHEST G'S VS INFLATOR STAGING TIME
● Inflator-Thiokol/Mercedes
● Passenger-3 yr. oldchild
● Position-6 in. cst-to-dash
● Bag Geom.-Phase II DMC
30 mph impact
static (no crash)
PEAK CHEST G'S - 3 MSEC CLIP
STAGING TIME - MSEC.
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0.00
2.50
5.00
7.50
10.00
12.50
15.00
17.50
20.00
22.50
25.00

Figure 4-4

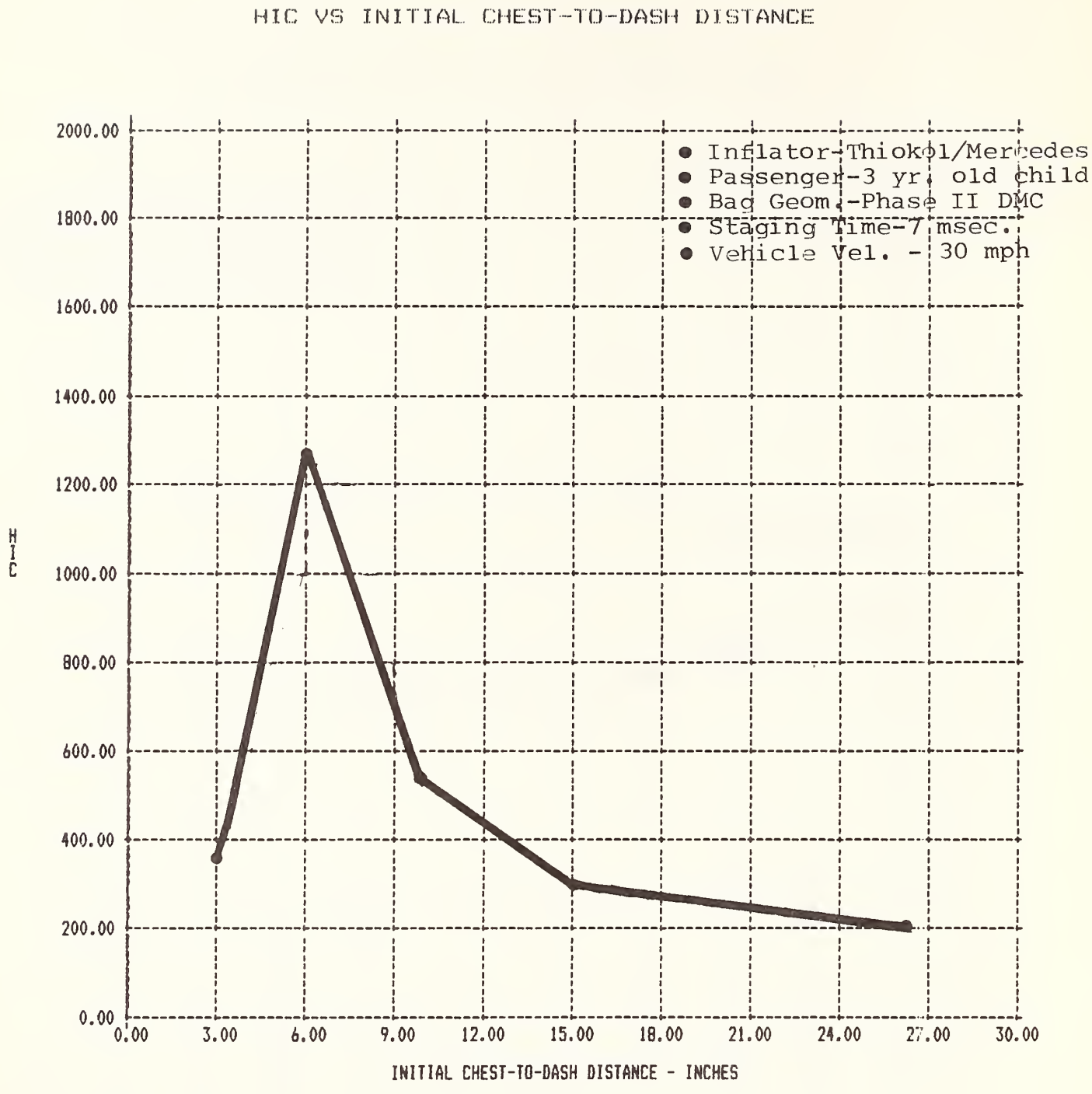

HIC VS INITIAL CHEST-TO-DASH DISTANCE
● Inflator-Thiokol/Mercedes
● Passenger-3 yr. old child
● Bag Geom.-Phase II DMC
● Staging Time-7 msec.
● Vehicle Vel. - 30 mph
HIC
2000.00
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00
30.00
INITIAL CHEST-TO-DASH DISTANCE - INCHES

Figure 4-5

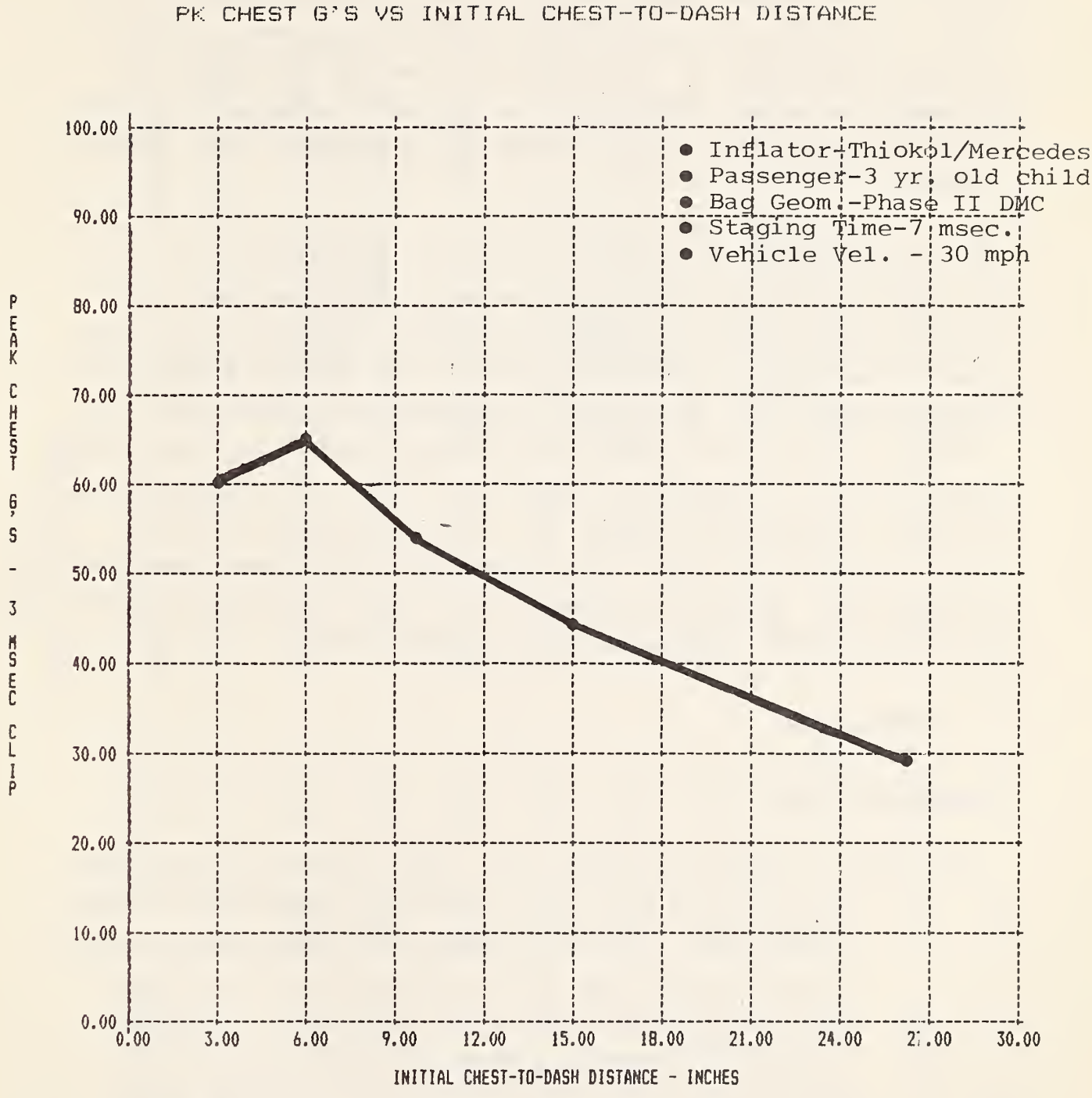

PK CHEST G'S VS INITIAL CHEST-TO-DASH DISTANCE
Inflator-Thiokol/Mercedes
Passenger-3 yr. old child
Bag Geom.-Phase II DMC
Staging Time-7 msec.
Vehicle Vel. - 30 mph
PEAK CHEST G'S - 3 MSEC CLIP
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00
30.00
INITIAL CHEST-TO-DASH DISTANCE - INCHES

Figure 4-6

with the 50th percentile adult male driver and passenger in Phase I, it seemed appropriate to begin our sled testing in the right front passenger position with this most critical design condition. In this way, if it turned out the child presented a major design problem, we could address it early in the test series while we still had plenty of time remaining.

In the following sections we will, for each individual test, describe the test objective, the test set-up and the test results. This should provide a detailed, cohesive account of what we set out to accomplish, how it was done and what the results were. For the reader's convenience we have also included a table which summarizes the pertinent test conditions and results for all twelve sled tests. The table, Table 4-1, provides information needed for a quick overview of the tests including all the injury measures. For a more detailed account, the reader is referred to the following sections in which the tests are discussed in greater depth.

4.3 Test No. 1

Test Objective

Driver: To ascertain whether the sled results would be typical of the car crash results for equivalent impact conditions. For this reason our first test with the driver system was with the same basic conditions that existed for the first car crash in Phase I; i.e. 50th percentile male at 35 mph frontal impact velocity with equivalent ACRS design. The only difference between this initial sled test

TABLE 4-1

SLED TEST RESULTS

TEST NO.	DUMMY SIZE	SPEED MPH	HIC	PK RES CST (-3 msec.)	Pk FEMUR LOADS Left	Right	REMARKS
1-D	50th	30	68	25g	1790#	1200#	Driver injury measures very low.
1-P	3 yr old	30	3279	71g	N/A	N/A	Injury measures high due to very high pt. of contact of bag on child due to acc. bag fold and dummy head construction (see pg. 4-19).
2-D	5th	30	214	33g	920#	1290#	Driver results again very good.
2-P	3 yr old	30	504	66g	N/A	N/A	Folded bag for 1'wr deployment. Much improvement but injury measures still high.
3-D	95th	30	1181	49g	1480#	1110#	95th percentile male too large for DeLorean compartment, head impacted header(see text).
3-P	3 yr old	30	379	54g	N/A	N/A	Increased inflator staging time from 7 to 17 msec, also used rolled under bag fold (this bag fold used hereafter). Inj. meas. reduced.
4-D	50th	30	121	32g	1360#	1090#	Again, results very good.
4-P	3 yr old	30	441	58g	N/A	N/A	Decreased inflator staging time to 13.5 msec. Injury measures increased slightly.
5-D	50th	30	115	29g	1805#	1760#	Repeat of last test. HIC almost identical, chest g's lower. Results still very good.
5-P	3 yr old	30	559	66g	N/A	N/A	Put staging time back to 17 msec; however injury measures still fairly high. Appeared vent may have become blocked.
6-D	50th	35	368	54g	1150#	1505#	Increased speed. Head impacted h'dr due to lack of head room causing higher injury meas. than would otherwise have occurred.

TABLE 4-1 (cont'd)

TEST NO.	DUMMY SIZE	SPEED MPH	HIC	PK RES CST (-3 msec.)	PK FEMUR LOADS Left	Right	REMARKS
6-P	50th	35	921	72g	2950#	1270#	First adult pass. test, 17 msec staging. Inflation too slow for adult, also aluminum skin on K.R. impeding knee pen.
7-D	50th	35	306	40g	1250#	1270#	Removed visor and pushed pass. down on seat to improve headroom. Worked, no hit.
7-P	50th	35	606	50g	1070#	1140#	Removed foam from seat to 1'wr pass. Also softened K.R. by slitting al. cover between knees & red. staging time to 7 msec. Results much improved
8-D	5th	35	328	50g	1400#	1250#	Injury measures low; rubber neck broken at bonded joint (see text).
8-P	5th	35	463	51g	1170#	1040#	Replaced seat. Injury measures O.K.
9-D	5th	30	203	39g	1190#	1095#	Another good driver test,(no passenger)
10-D	5th	30	147	32g	1260#	1050#	Boosted driver 3/4 inch by putting a little foam under seat. Injury measures very low.
10-P	50th	30	256	39g	950#	1020#	Still 7 msec staging. Inj. Meas. low.
11-P	3 yr old fwd. pos.	30	764	*59g	N/A	N/A	First child test @ 7ms staging & rolled under bag fold. Also boosted on seat 1½ inches. No real change; results marg.
12-P	3 yr old fwd. pos.	30	714	*59g	N/A	N/A	Same as #11 except lowered H-P by sitting child directly on seat. Results marginal.

*see page 4-70.

and the crash test was that in the crash test the steering column was prevented from stroking whereas, for this test, the column was allowed to stroke.

Passenger: To determine whether the passenger ACRS as presently configured would result in potentially severe injury for the forward positioned child for the conditions indicated as critical in the Phase II computer simulations.

Test Set-up

General: Test Velocity - 30 mph

Driver: Restraint System - As described in Section 2.0.
Seat Position - Mid.
Steering Column - Free to stroke, no DeLorean shroud covering keylock.
Dummy Size - 50th percentile male (Fig. 4-7A)

Passenger: Restraint System - As described in Section 2.0.
Seat Position - Mid.
Inflator Staging Time - Baseline @ 7 msec.
Dummy Size - 3 yr. old child (Fig. 4-7B)
Bag Fold - Accordian
Position - Six inches, chest-to-bag

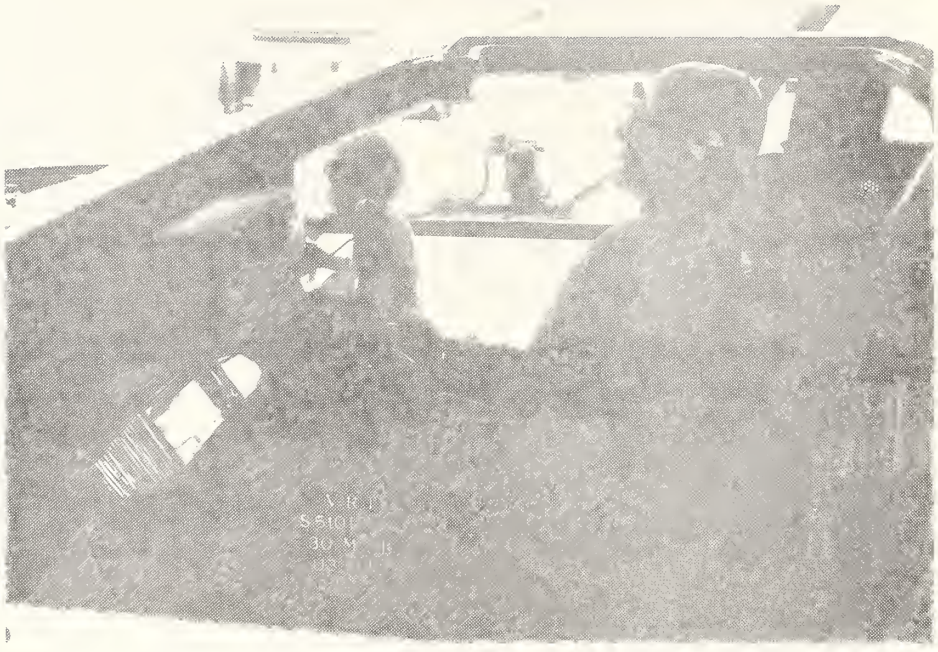


Figure 4-7A. Pre-test-Driver

Figure 4-7B. Pre-test,Passenger

Test Results

Driver: The injury measures for the driver were quite low as predicted by the Phase II computer simulations. The table below shows this comparison for the 30 mph frontal impact condition with 50th percentile male and the subject driver ACRS.

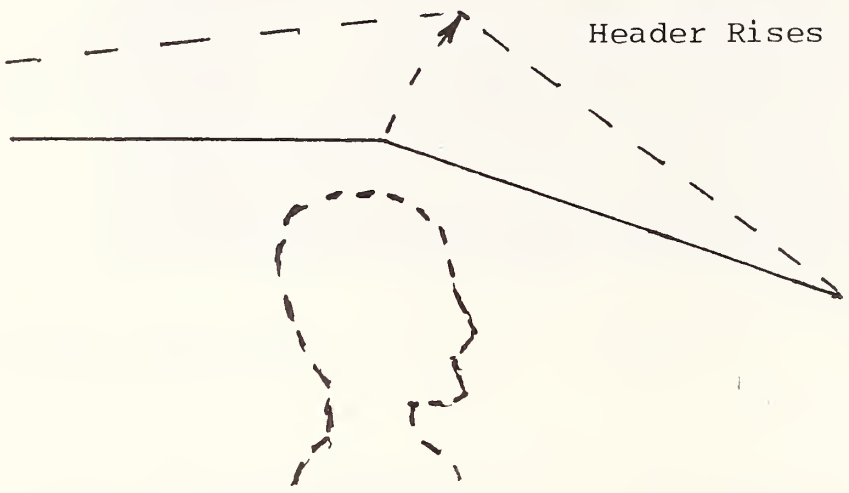
	Phase II Computer Simulation	Phase III Sled Test No. 1
HIC	200	68
Pk Chest G's (-3 msec)	25	25
Pk Femur Loads	1200#	L:1790# R:1200#

Although the injury measures were quite low as was predicted for this first sled test, the driver trajectory was much different than the crash test. Since the computer input file was set up based, in part, upon the trajectory observed in the Phase I crash test, this may serve to explain some of the variation that exists between the Phase II simulation and the Phase III sled test. Let us now address the question as to why the trajectory for the driver is different for the sled test than what was observed in the Phase I crash test.

In this Phase III sled test the driver head grazes the windshield header; however in the Phase I car

crashes, two things occur that prevent contact of the occupant's head with header (abnormally close to the head in the DeLorean) and the windshield.

First, the A-pillar rotates about the A-post juncture toward the struck object lifting the header as it goes (see below). Secondly, the X-frame center spine buckles,



breaking the fiberglass body at the B-post-floor pan juncture (Figure 4-8) thereby driving the floor downward. This combination of the A-pillar rising and the floor and seat being driven downward coupled with the occupant submarine tendency caused by the correspondingly higher airbag/chest contact point, results in the 50th percentile's head clearing the header by approximately one foot in the full scale car crash tests.

However, in the sled test environment these two deformation patterns cannot occur so that head/header impact becomes a very real possibility in the "low slung" DeLorean compartment.

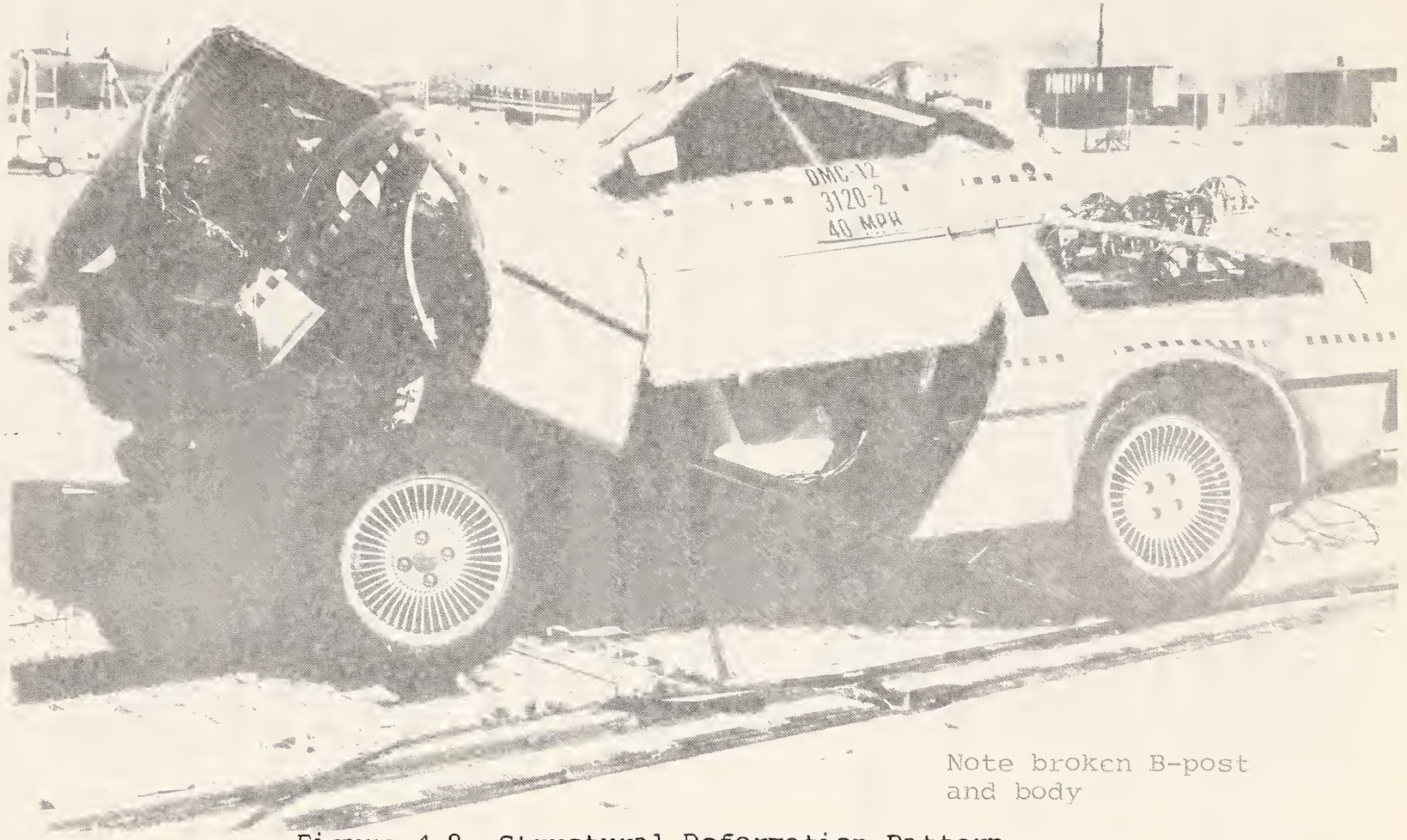


Figure 4-8. Structural Deformation Pattern

As a consequence, whereas in the car the occupant's head would miss the header by approximately one foot, in this sled test, the 50th percentile male dummy head actually grazes the header. As a result of this first test, we could see that the head of the 95th percentile male would present real problems in this sled test environment (this will be discussed more in the Test No. 3 description).

In this first sled test, the DeLorean column shroud that covers the keylock area was purposely left off to ascertain whether the column stroking properties would be best without the hindrance posed to stroking by the shroud. It was decided after evaluating the results of this test that the chest g's were so low that the addition of the shroud would not increase chest g's to the point of criticality and would, in fact, provide for more energy absorption which would help at the higher impact velocities. For these reasons, the DeLorean column shroud was left on for all subsequent tests.

The coumn stroke was three inches and the Volvo wheel crush was one-eighth inch for this test. The DeLorean column has a friction clamp type of tilt adjust mechanism which is set by tightening a thumb screw. For this test the column tilt adjustment was set in its mid position which results in a 15 degree column angle (measured from horizontal). The thumb screw was tightened by hand as tightly as possible. During this test the tilt adjust friction lock slipped, allowing the

column to rotate to the "full up" position. To eliminate the effect of this undesirable slippage and its variable effect from further tests, the column was welded in the mid position hereafter (see Figure 4-9A for post-test view).

Passenger: It became apparent after sitting the three year old child in the DeLorean compartment for the first time that the airbag was going to impact the child very high on the body with the probable result that there would be severe rearward rotation about the H-point. Nevertheless, we went ahead with test preparations folding and stowing the bag exactly as done in the successful Phase I vehicle crash tests.

The results were not entirely unexpected. The child dummy rotated severly backward about the H-point and had the very high HIC and moderately high chest g's shown in Table 4-1. (see Figure 4-9B for post-test view).

One thing that became apparent after examining the data however, is that the construction of the three year old dummy head influences the magnitude of the HIC to a great degree. Unlike the adult dummy sizes or even the six year old child dummy, the three year old dummy head and chest is made of a plastic type material with accelerometer mounts fastened directly to this material. When the bag impacts the child in the head/upper chest area, it sets up an elastic vibration that is especially severe in the head cavity. This elastic response may be seen in all the three year old head data presented with all of the test data in Appendix A.

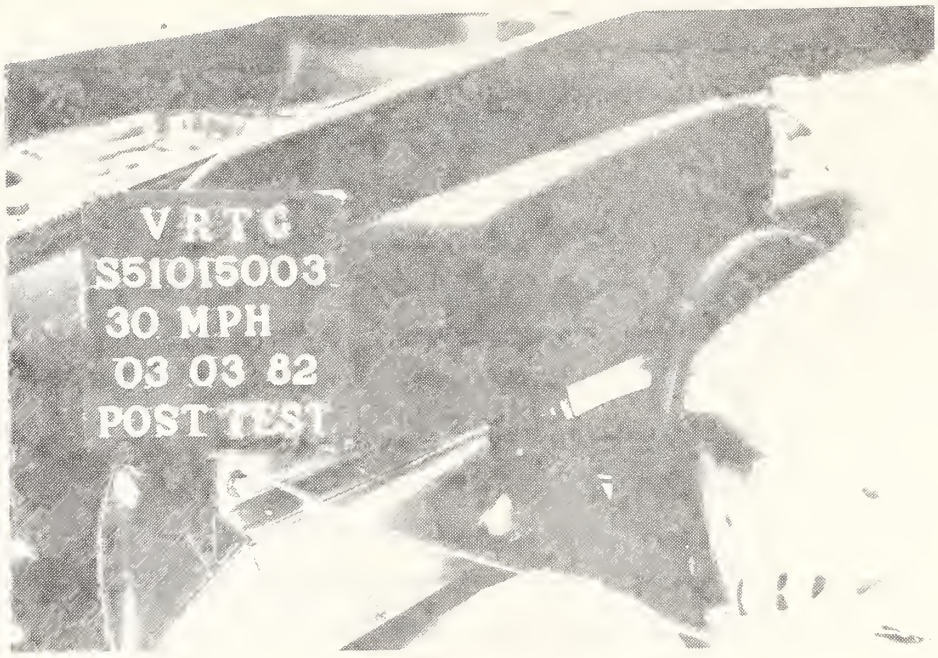


Figure 4-9A. Bent Cowl Shows Evidence of Maximum Column Rotation

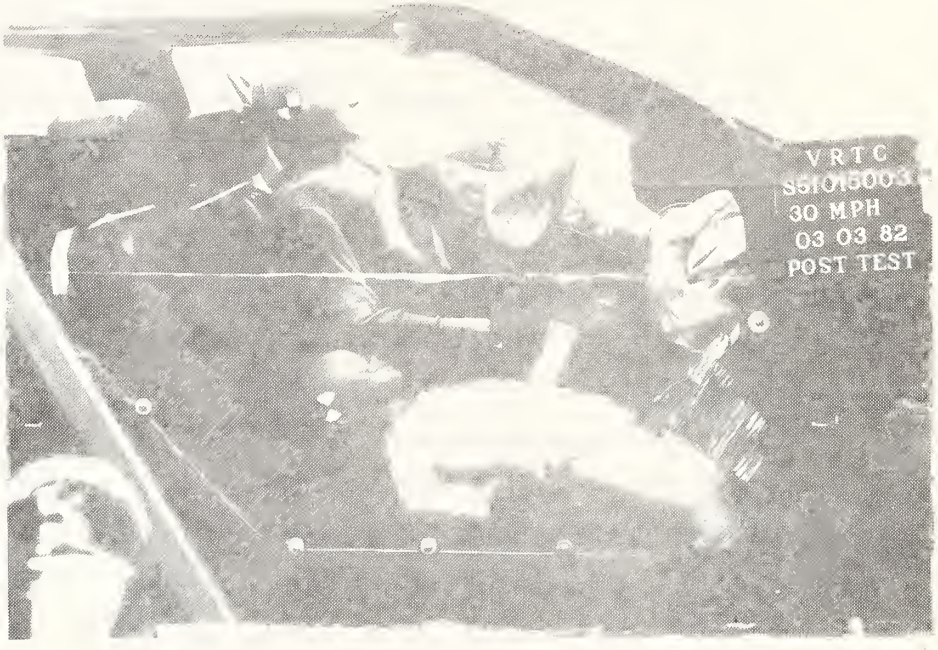


Figure 4-9B. Passenger, Post-test Position

Even the head "Y" direction trace which is normal to the direction of airbag deployment and the resulting direction of dummy movement is excited by airbag impact. As may be seen in the head y-trace for Test No. 1, the magnitudes of the g level peaks are in excess of 80 g's in both the positive and negative directions. Naturally,since there is no net y-direction movement, the g level excursions are in both the positive and negative directions with the net acceleration corresponding to approximately zero g's. However in the HIC computation both plus and minus g levels contribute equally. Thus it is possible to have a vibratory response set up in the head that has a time averaged net acceration of zero but influences the HIC computation greatly. Further the entire vibratory response may be due to having a head made of a material that is far different than the human equivalent. For the purpose of illustrating this point we have "hand filtered" the vibratory portion of the head response curve and then "faired" this curve into the remaining part of the curve unaffected by this vibratory response. The resulting HIC is computed as 2391 which is somewhat less than the 3279 computed with the vibratory response unfiltered.[1]

Although the HIC may be somewhat higher than it should be due to the dummy head construction, it is still much too high and some means of attenuating these high g levels in the head is desired. One method which we have successfully used in the past is to modify the

[1]For purposes of illustration, Appendix B shows the effect of "equivalent" hammer blows to each of the dummy heads. It is apparent from this that the 3 yr old behaves abnormally.

bag fold so that the bag deploys lower thereby lessening the rotational velocities of the dummy anatomical components. To accomplish this the bag fold was modified as described in the "test set-up" section for Test No. 2.

4.4 Test No. 2

Test Objective

Driver: To ascertain whether the lower extreme in potential driver sizes would be protected within the injury criteria limits as predicted by the Phase II computer simulations.

Passenger: To determine whether a bagfold technique that causes a lower effective strike point on the child will result in a significant lessening of the HIC.

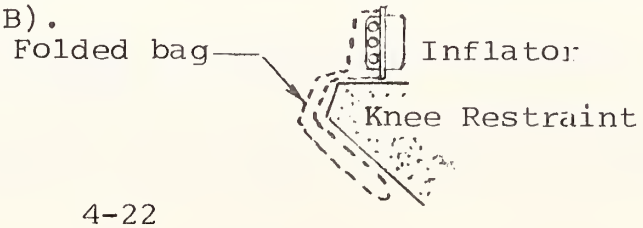
Test Set-up

General: Test Velocity - 30 mph

Driver: Restraint System - Same as Test No. 1 except:

a) column tilt adjust welded at mid adjust position
b) added DeLorean column shroud.
c) moved seat forward two inches to accomodate 5th percentile female (see Figure 4-10A)

Passenger: Same as Test No. 1 except bag fold as shown below. (see Figure 4-10B).



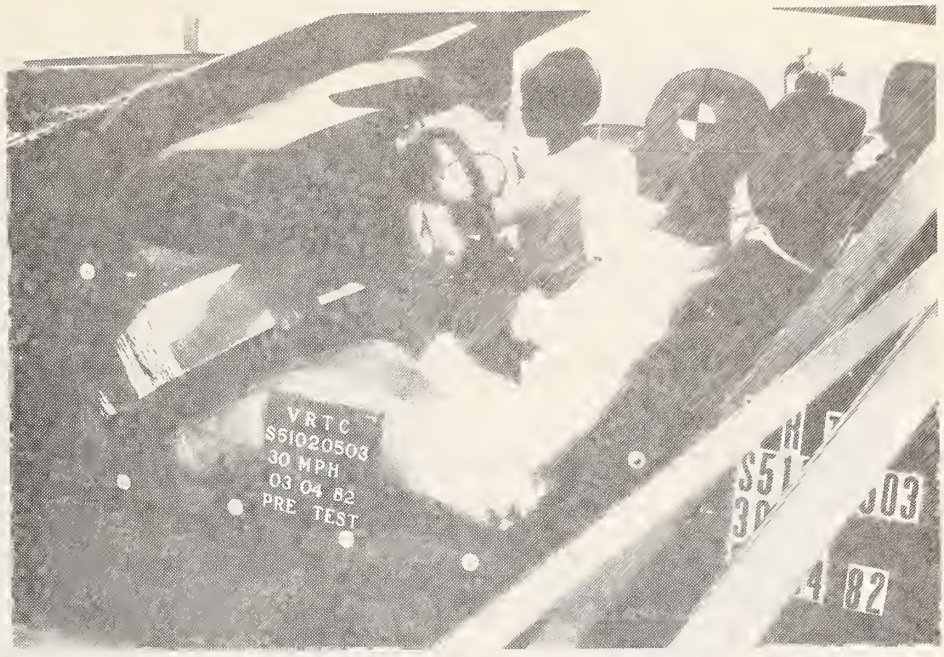


Figure 4-10A. 5th Percentile Female Driver

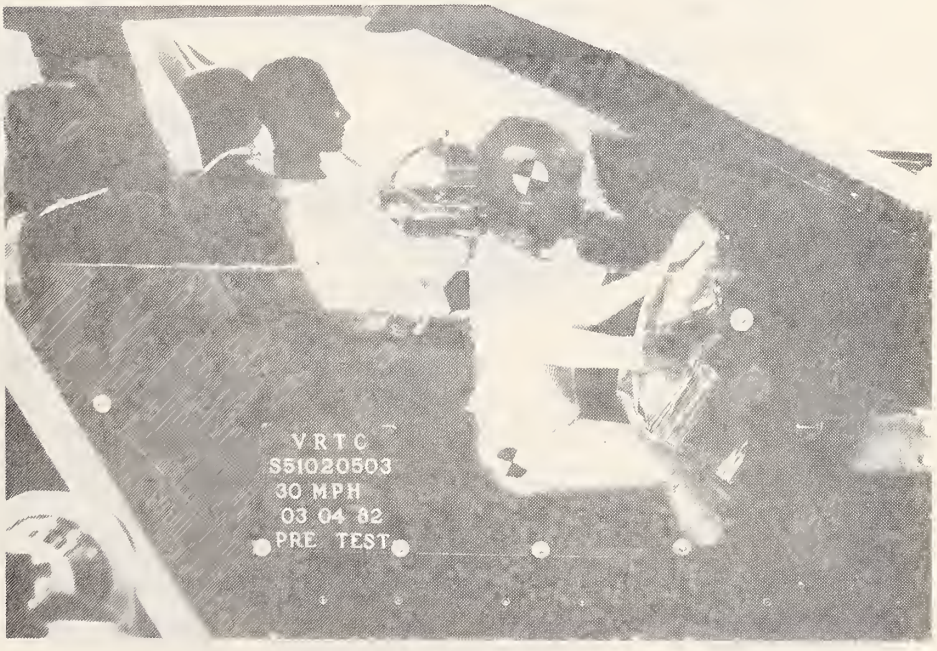


Figure 4-10B. Forward Positioned Child with Modified Bag Fold

Test Results

Driver: Once again the driver injury measures were quite low as shown by Table 4-1. Since no computer simulations had been made for the 5th percentile female at 30 mph in Phase II, no comparison of injury measures could be made. Figure 4-11A shows the post-test view.

Passenger: The only item changed since the last test was the method of bag folding so here we had an opportunity to verify or disprove our theory that a bag fold technique which would result in a lower placement of the bag on the child would reduce the HIC appreciably.

The results were striking. Although the undesirable oscillatory effect inherent in the plastic/composite head was still present, it was readily apparent that the magnitude of the overall head acceleration was much reduced (see table below, also Fig. 4-11B for pos'n)

	Phase II Computer Simulation	Phase III Sled Test No. 2
HIC	*1286	504
Pk Chest G's (-3 msec)	65	66

*As may be seen by Figure 4-5, the HIC is very sensitive to distance of the chest from the initial airbag position which in turn is influenced by the height of the H-point off the floor. Thus relatively minor changes in this height have a great influence on the HIC. Also, this HIC value assumes an accordian bag fold which was not used in this test.

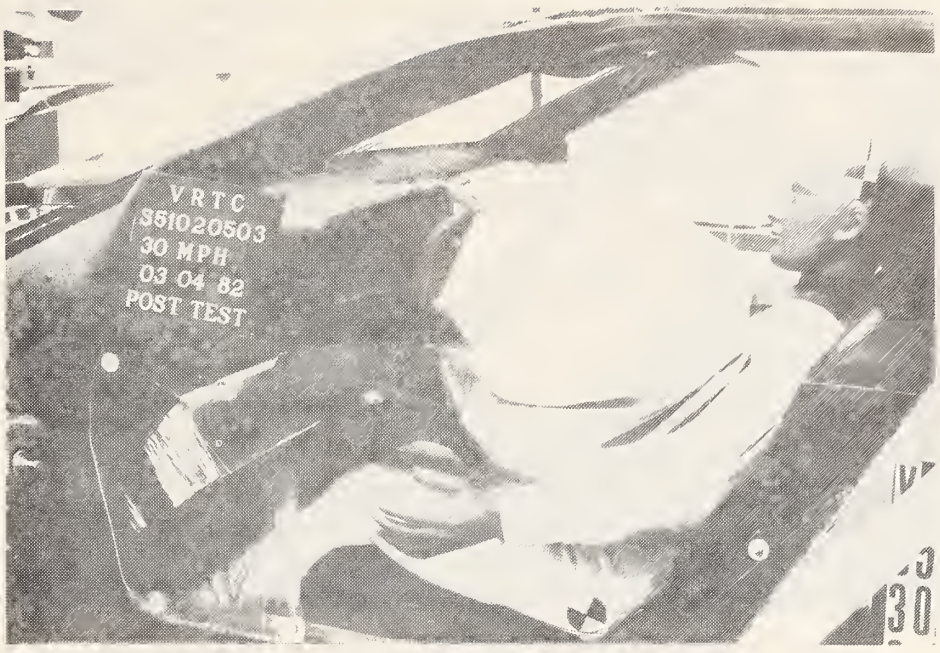


Figure 4-11A. Post Test Driver View

Figure 4-11B. Post Test Passenger

Although the new bag fold technique worked well in terms of reducing the head g's, the bag did not deploy fully in the upward direction as the knees pinched a portion of the bag against the knee restraint. Because of this, the bag fold was modified for Test No. 3.

4.5 Test No. 3

Test Objective

Driver: To ascertain whether the upper extreme in possible driver sizes (the 95th percentile male) would be protected to the extent that the injury measures would be well within the criteria limits.

Passenger: To determine whether the "rolled under" type of bag fold would cause the airbag to impact the forward positioned child desirably low on the chest but not so low that the airbag becomes trapped between the knees and the knee restraint as it did in Test No. 2.

Test Set-up

General: Test Velocity - 30 mph

Driver: Same as Test No. 2 except:

a) 95th percentile male.

b) Seat moved all the way to the rear. Figure 4-12A shows the lack of compartment headroom for the 95th percentile male.

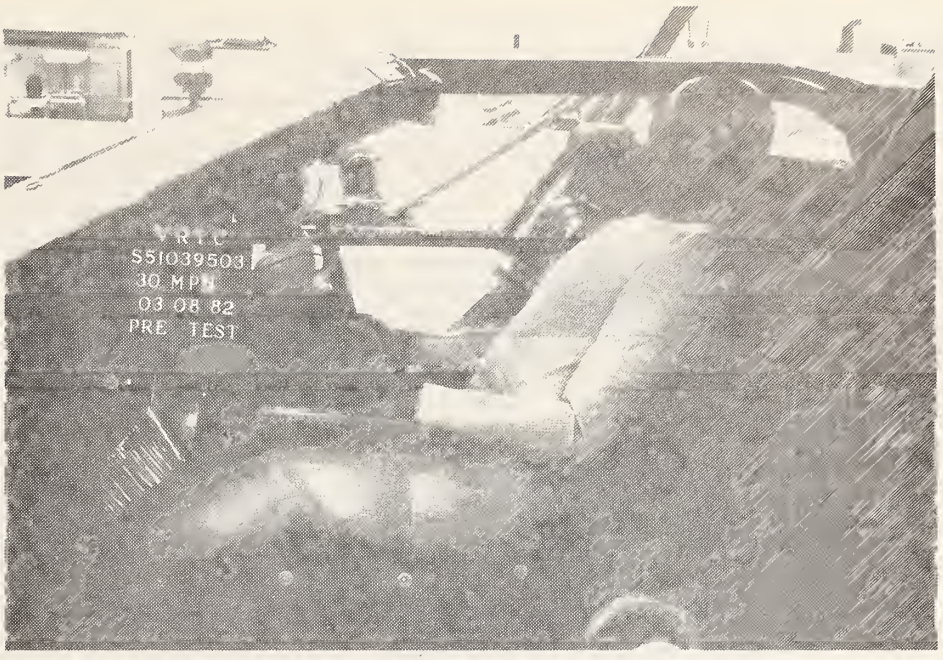


Figure 4-12A. Pre-Test, Driver

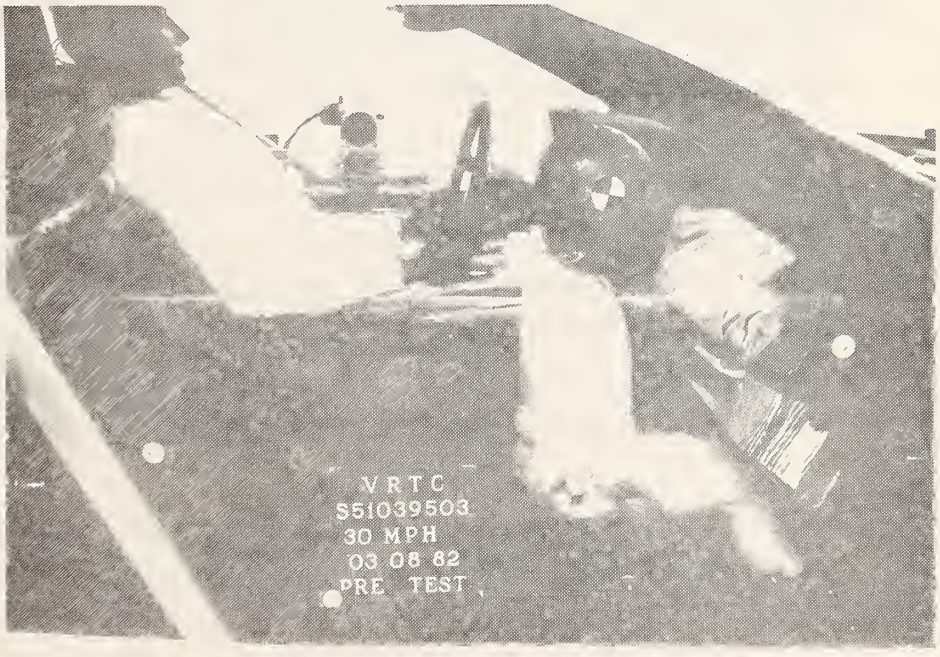


Figure 4-12B. Pre-Test, Passenger

Passenger: Same as Test No. 2 except:

a) Used "rolled under bag fold as shown in Figure 4-12B.

b) Increased inflator staging time from 7 to 17 msec in an effort to attenuate chest g's.

Test Results

Driver: The 95th percentile male driver's head impacted the header at a point on the driver's head approximately one-half the distance between the bridge of the nose to the top of the head; i.e. right in the center of the forehead. It appeared from the results of this test that we would not be able to sled test the 95th percentile male in the DeLorean compartment. However, for the reasons stated on pages 4-15 to 4-18, it is probable that in an actual DeLorean crash, the head would not strike the header.

Because of this head strike, the HIC was in excess of the criteria limit at 1181. In addition, the chest g's were also higher than we expected. This also may be attributed to the head strike as a sudden rise in chest g's occurs just after the head strikes the header (see Appendix A, Test No. 3 and Table 4-1).

The column stroked 2½ inches and the wheel crushed ½ inch at the bottom of the wheel rim.

Passenger: The "rolled under" bag fold worked very well when combined with the 17 msec inflator staging time; however we suspected that this increased staging time could have an adverse effect on the normally seated adult since the amount of "ride-down he receives would be reduced due to the slower bag inflation. Because of this concern, we decided to reduce the staging time slightly prior to the next test.

The table below compares the Phase II computer prediction with the actual test results. The computer however assumed an "accordian" bag fold but, as stated above, a "rolled under bag fold was actually used. A rolled under bag fold normally results in lower HIC values as the bag deploys somewhat lower on the body.

	Phase II Computer Simulation	Phase III Sled Test No.2
HIC	600	379
Pk Res Cst G's (-3 ms)	62	54

Figure 4-13 shows the post-test dummy positions.

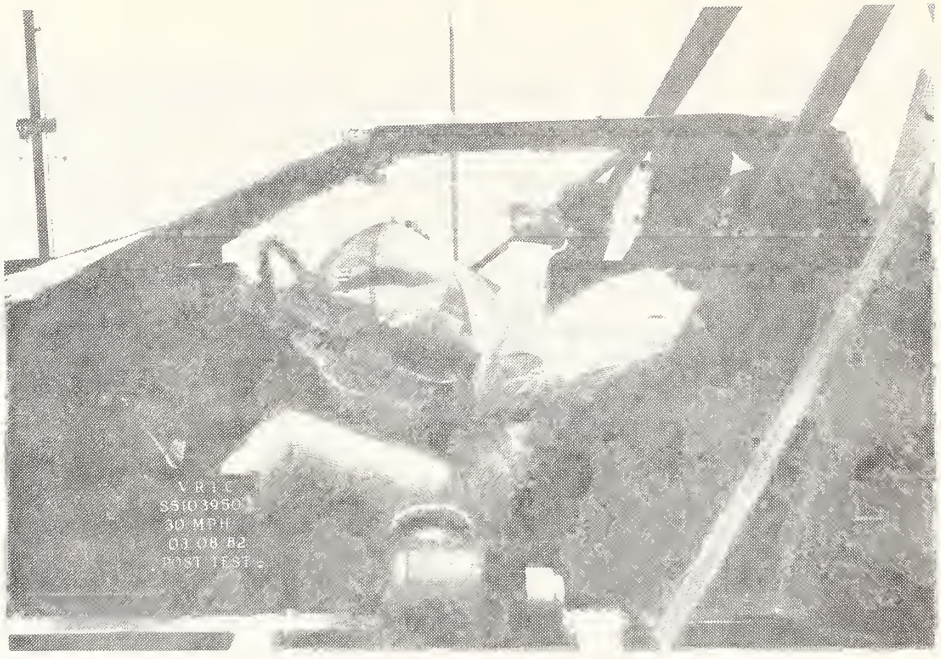


Figure 4-13A. Post-Test Driver View

Figure 4-13B. Post-test Passenger View

4.6 Test No. 4

Test Objective

Driver: To see how much having the DeLorean column shroud affects the test results as compared to Test No. 1 without the shroud.

Passenger: To determine the effect of reducing the inflator staging time from 17 to 13.5 msec.

Test Set-up

General: Test Velocity - 30 mph

Driver: Same as Test No. 3 except:

a) 50th percentile male (Figure 4-14A).

b) seat moved to mid position.

Passenger: Same as Test No. 3 except the inflator staging time decreased from 17 to 13.5 msec. Also in this test and the last test, the chest to airbag distance was 4 3/4 inches and 4 inches respectively. Figure 4-14B shows the pre-test dummy position.

Test Results

Driver: The 50th percentile male ATD's head scraped the header as in Test No. 1; however this effect on overall injury was slight. Since the overall injury measures were

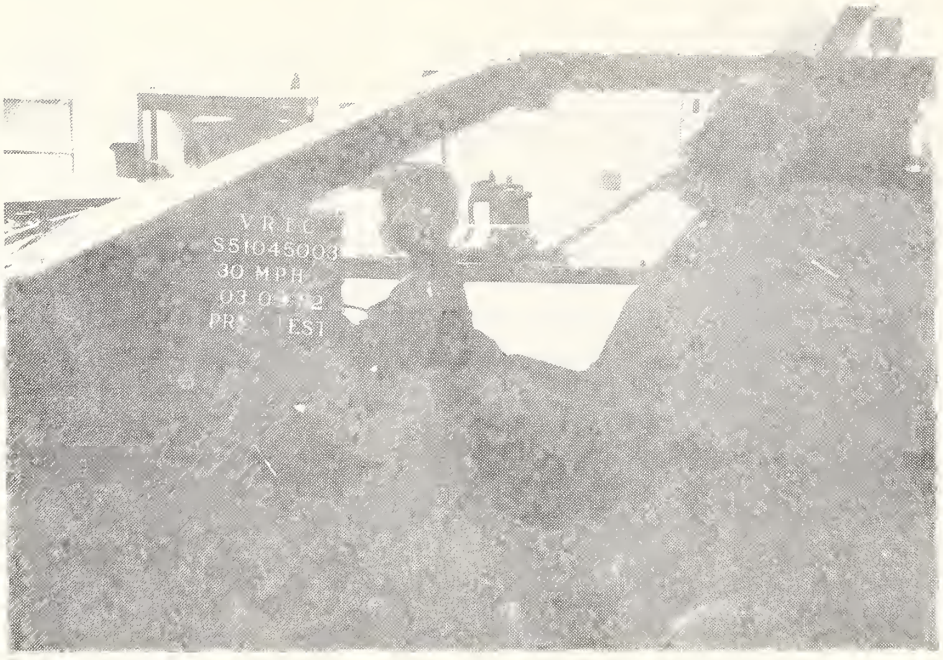


Figure 4-14A. Driver, Pre-Test

Figure 4-14B. Passenger, Pre-Test

quite low, we again confirmed our earlier decision to retain the DeLorean column shroud as we thought the added resistance it provides to column stroking through its interaction with the knee restraint would prevent "bottoming" of the steering column in high speed impacts.[1]

The column stroked 2 3/4 inches and the steering wheel crushed 1/2 inch at the rim bottom. The table below compares the results of this test with the Phase II computer simulation.

	Phase II Computer Simulation	Phase III Sled Test No. 4
HIC	200	121
Pk Res C'st G's (-3 ms)	25	32
Pk Femur Loads	1200#	L:1360# R:1090#

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[1] The column shroud was left on the column for the Phase I, 46 mph crash test with the DeLorean at Dynamic Science. The column stroked approximately 8 inches total (6 inches due to dummy loading and 2 inches due to firewall intrusion).

Since the Phase II computer results did not include the effect of the column shroud impeding column stroke, the chest g's are slightly less in the simulation than in the actual sled test.

Figure 4-15A shows the post test driver position.

Passenger: Increasing the inflator staging time to 13.5 msec seemed to cause a slight increase in the injury measures (or possibly the increase was just due to normal data scatter). The second passenger inflator fired approximately two msec after the bag touched the dummy chest and during the time of maximum flow from the first inflator. This may have caused the chest g spike seen in the chest data. We therefore decided to go back to the 17 msec staging time prior to the next test.

Even though the results were higher than we would have liked to have seen, the results for both this test and the preceding test were below the injury criteria limits and, in fact, not too different from what the Phase II computer simulations predicted for the forward positioned child in the critical condition of 4 to six inches from the bag and in a crash situation.

	Phase II Computer Simulation	Phase III Sled Test No. 4
HIC	800	441
Pk Res C'st G's(-3 ms)	63	58

Figure 4-15A. Driver, Post-Test

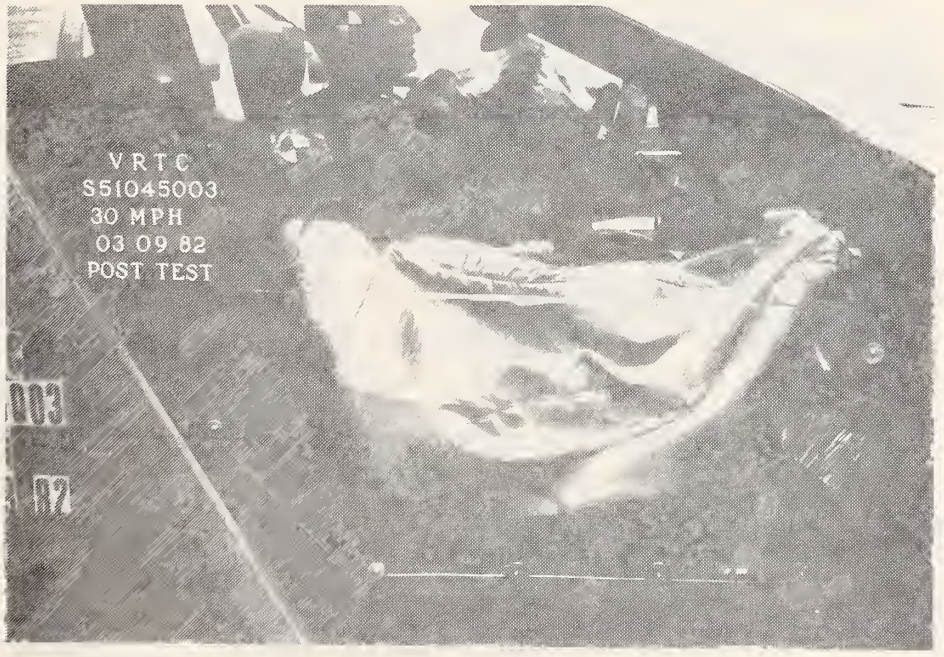


Figure 4-15B. Passenger, Post-Test

4.7 Test No. 5

Test Objective

Driver: To repeat the last test as closely as possible so as to obtain the data "scatter" that exixts in attempted test repetition. This will be used to determine the computer simualtion accuracy we may expect from our models; obviously, the simulation fidelity based upon a mathematical representation of a real event cannot be more accurate than the human ability to reproduce the event. That is, the degree of accuracy to which we may measure or otherwise determine a set of test conditions has to be greater than the degree of simulation fidelity that is a result of using these same measurements to set up the computer input file used to replicate this same test.

Passenger: To determine whether a reduction in the forward position child injury measures will result from increasing the inflator staging time back to 17 msec. (we still have a concern that this rather late staging time of 17 msec may be detrimental to normally seated adult performance; however if the injury measures for the child were sufficiently low, this higher staging time might still be an attractive option.

Test Set-up

General: Test Velocity - 30 mph

Driver: Same as last test. Figure 4-16A shows the driver pre-test position.

Figure 4-16A. Driver, Pre-Test

Figure 4-16B. Passenger, Pre-Test

Passenger: Same as last test except inflator staging time increased to 17 msec. Figure 4-16B shows the passenger pre-test position.

Test Results

Driver: The table below compares the results of this test with the results of the previous test.

	Test No. 4	Test No. 5
HIC	121	115
Pk Res. Chest G's (-3 msec)	32	29
*Femur Loads-Lb Left, Right	1100, 750	1100, 1130
Column Stroke -Inches-	2 3/4	2 3/4
Wheel Crush -Inches-	1/2	1/4

As may be seen by comparing the above results, the degree of agreement between the tests was good. The

*These femur loads do not include high frequency spikes of less than 1-2 msec duration; however those in Table 4-1 do include such spikes.

Maximum deviation was in femur loads which, on the average had a deviation about mean of plus and minus 10 percent. The chest g's had a deviation of approximately plus and minus 5 percent while HIC only varied plus and minus 2.5 percent about the mean for the two tests.

We therefore tentatively conclude (tentatively since we only have two identical tests to base this conclusion on) that a computer simulation of a particular test cannot be expected to deviate less than approximately plus or minus 2.5 to 10 percent from the actual test values. Thus a computer validation run which only varies 2.5 to 10 percent from the mean of the actual test values is the best that can be expected.

Section 5 of this report discusses the results of a comparison between these test results (tests 4 and 5) and the computer simulation of these same tests.

Figure 4-17A shows the driver post-test position.

Passenger: The passenger test results are shown in Table 4-1. As can be seen, the chest g's have increased since the last test leading us to conclude that increasing the staging time is not having the desired effect of reducing the child's chest g's. However, at this point we decided to go ahead and investigate the performance of the 50^{th} percentile dummy size for the 17 msec staging time to either confirm or disprove our suspicion that the 17 msec staging time may not provide enough

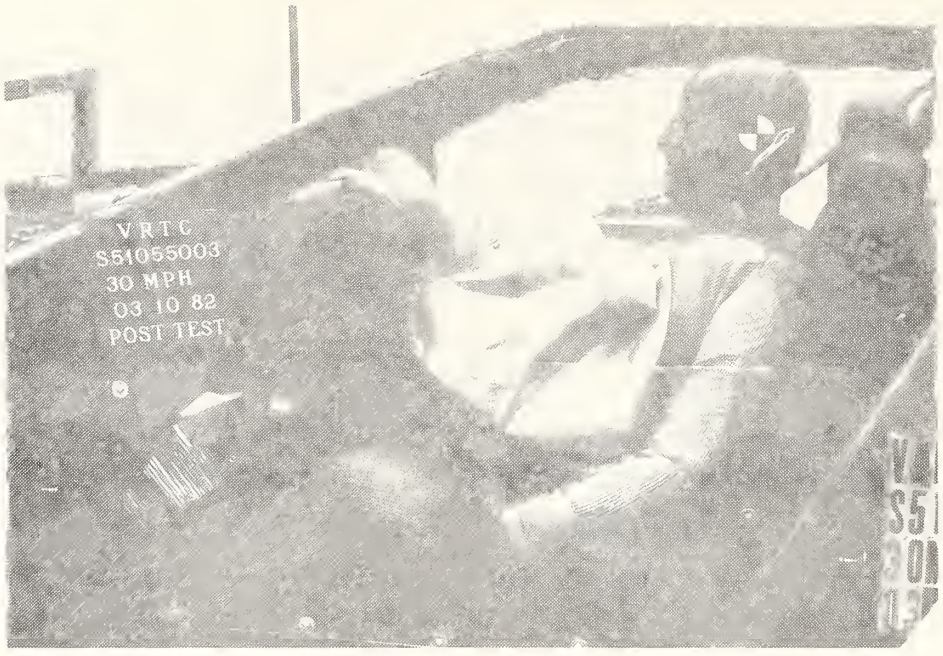


Figure 4-17A. Driver, Post-Test

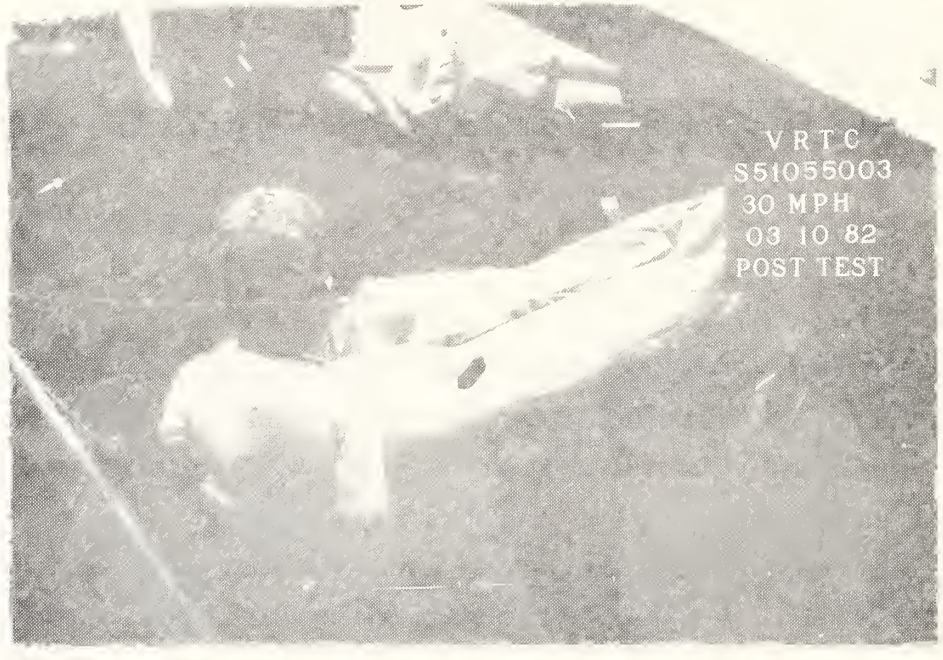


Figure 4-17B. Passenger, Post-Test

"ride-down" for the adult passenger sizes.

Figure 4-17B shows the passenger post-test position.

4.8 Test No. 6

Test Objective

Driver: To verify that this latest version (as compared to the Phase I vehicle test version in which the column was prevented from stroking) of the driver restraint system would produce injury measures well within the injury criteria limits at the increased speed of 35 mph.

Passenger: To determine whether an adult size passenger would be protected within the injury criteria limits by a system that had a relatively late firing of the second inflator (17 msec staging). The concern here was that 17 msec staging might cause a significant loss in the percentage of total passenger kinetic energy via "ride-down" because 17 msec was too long a time to wait to fire the second inflator.

Test Set-up

General: Test Velocity - 35 mph

Driver: Same as last test except speed increased to 35 mph. Figure 4-18A shows 50th percentile driver pre-test position.

Figure 4-18A. Driver, Pre-Test

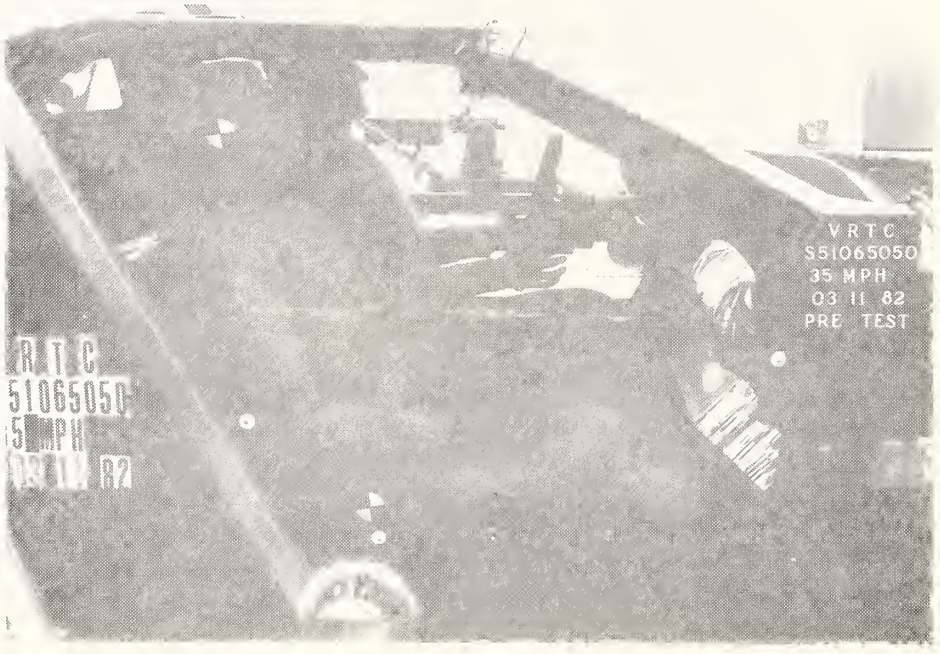


Figure 4-18B. Passenger, Pre-Test

Passenger: Same as last test except speed increased to 35 mph and 50th percentile male ATD substituted for 3 yr old child. Figure 4-18B shows the passenger pre-test position.

Test Results

Driver: As shown in Table 4-1, the injury measures were well within the criteria limits; however, unlike the equivalent vehicle crash conducted in Phase I, the dummy head scraped the header again. This again shows just how little head room exists in the DeLorean compartment and how different the driver trajectory is - sled vs crash. The steering column stroked 3 5/8 inches and the steering wheel crushed 1 3/8 inches for a total combined crush of 5 inches. Figure 4-19 shows the post-test results.

Passenger: As suspected, the 17 msec staging time between inflator firings was too much. The passenger penetrated the bag rather deeply and the restraint forces were slow to build up resulting in rather high, late peaking g levels for the head and chest. We therefore conclude that the 17 msec staging time is too great and will reduce this staging time prior to the next test.

A second thing learned in this sled test that is of some importance is that the femur loads are higher than we would like. The reason for this is due to a "tension bridge" forming between the knees due to the method of knee restraint construction. The sketch shown on the following page serves to illustrate the problem.

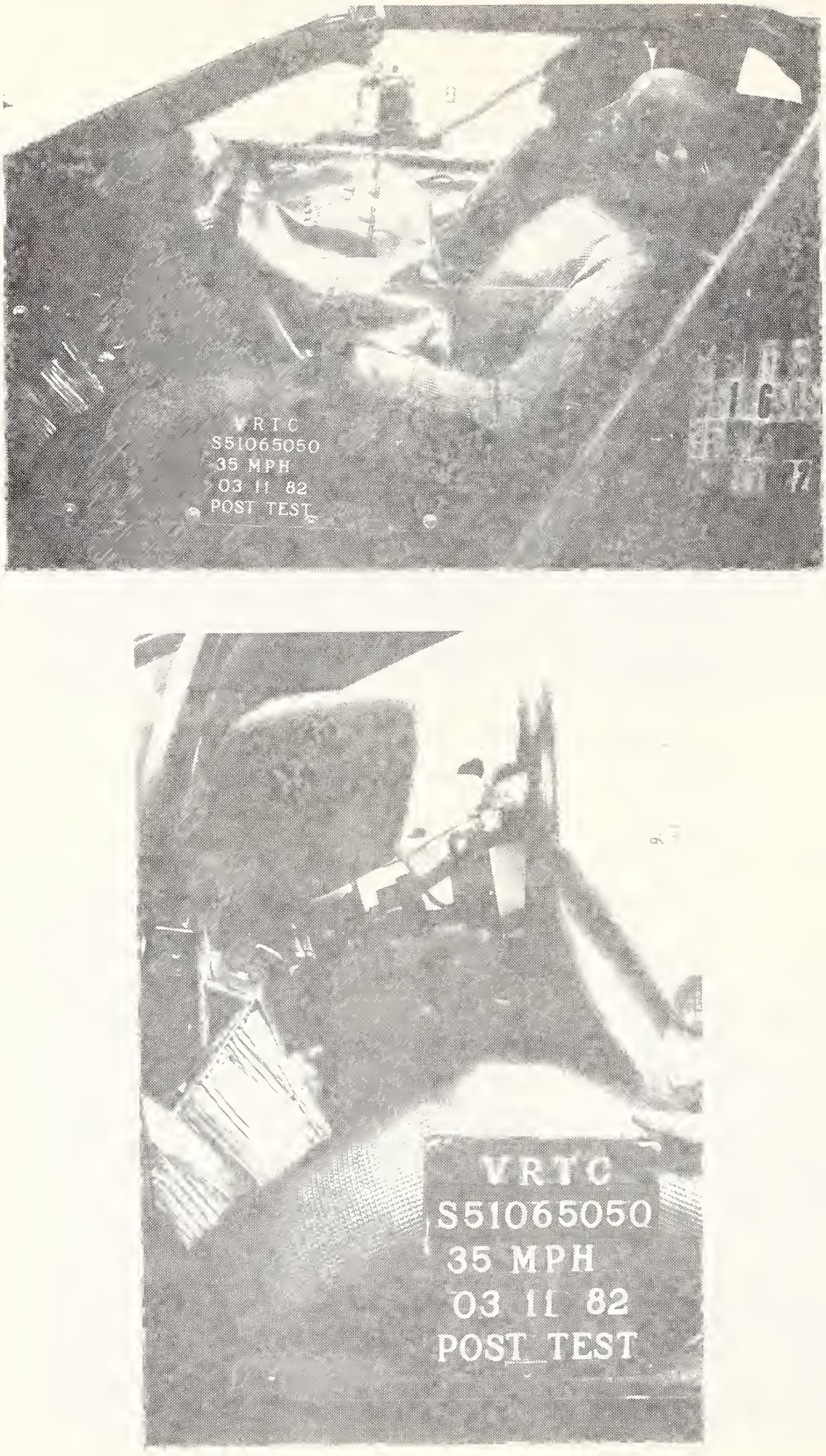
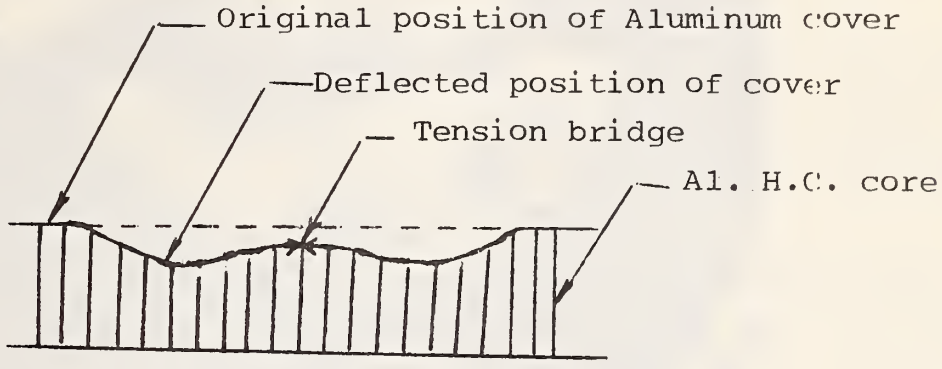


Figure 4-19. Driver, Post-Test

Formation of Tension Bridge in Aluminum Knee Restraint Cover



As the knees penetrate further and further into the knee restraint, a tension force is produced in the captive aluminum skin as it tries to crush an ever increasing area of honeycomb core. In order to allieviate this problem, it was decided to slit the aluminum cover skin between the impact point of the two knees at the approximate point at which the bridge was forming. In this way the cover skin could separate during the period of high knee penetration so that the honeycomb core area between the knees would not have to crush (this was done in all tests after this one and this problem never recurred).

Figure 4-20 shows the passenger post-test position.

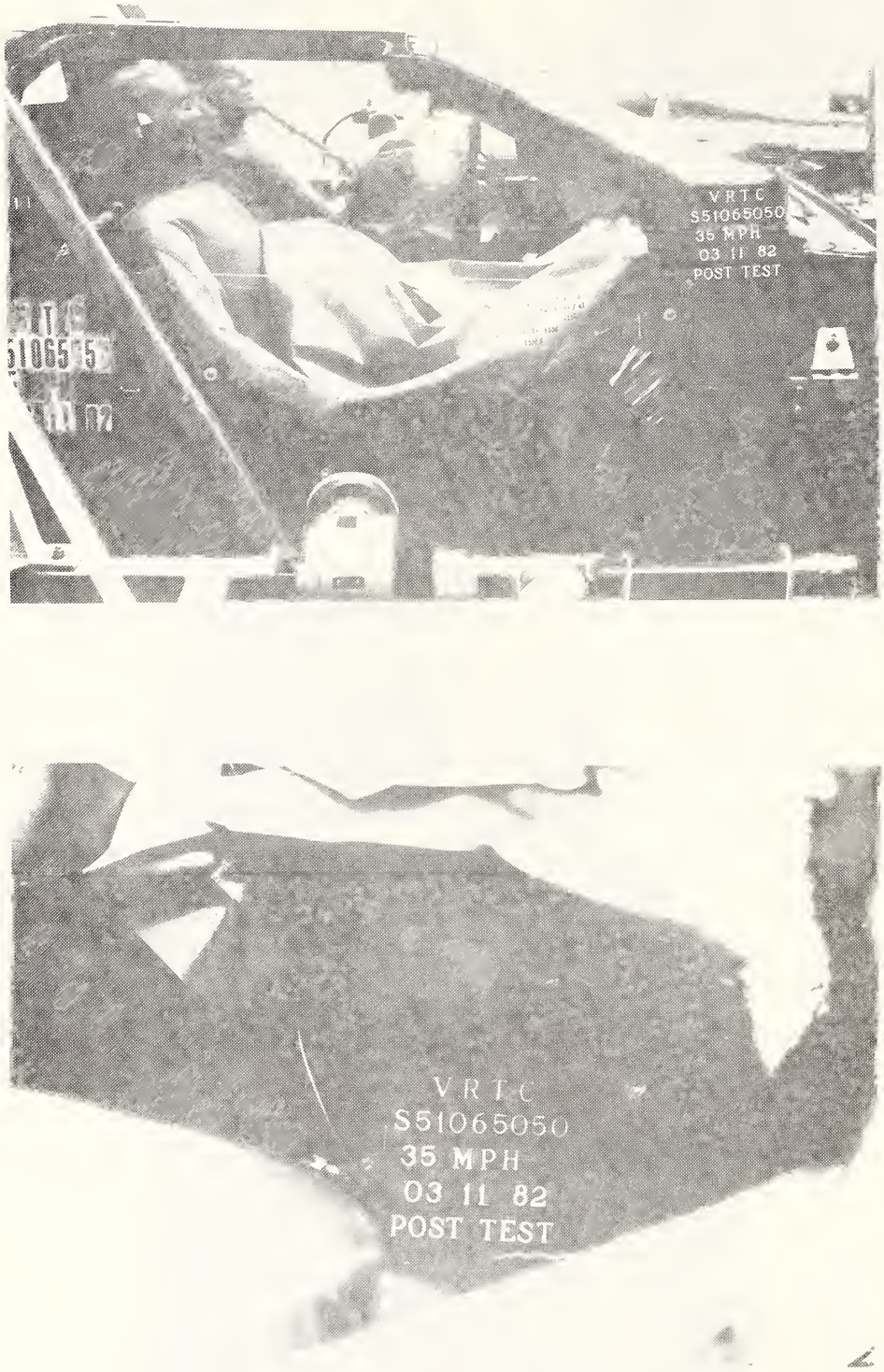


Figure 4-20. Passenger, Post-Test

4.9 Test No. 7

Test Objective

Driver: To repeat Test No. 7 except for the fact that the 50th percentile dummy was pushed down in the seat a little more in an effort to enable his head to clear the header.

Passenger: To determine whether a decrease in staging time would have the anticipated effect of lowering injury measures by increasing the amount of passenger kinetic energy absorbed in ride-down.

Test Set-up

General: Test Velocity - 35 mph

Driver: Same as last test except 50th percentile driver pushed down in seat a little more. Figure 4-21A shows the driver pre-test position.

Passenger: Same as last test except:

a) decreased staging time back to 7 msec (same as used in Phase II computer simulations.

b) slit aluminum cover on knee restraint to prevent "tension bridge" from forming (as discussed in results for Test No. 6).

c) lowered H-point by removing some foam from seat.

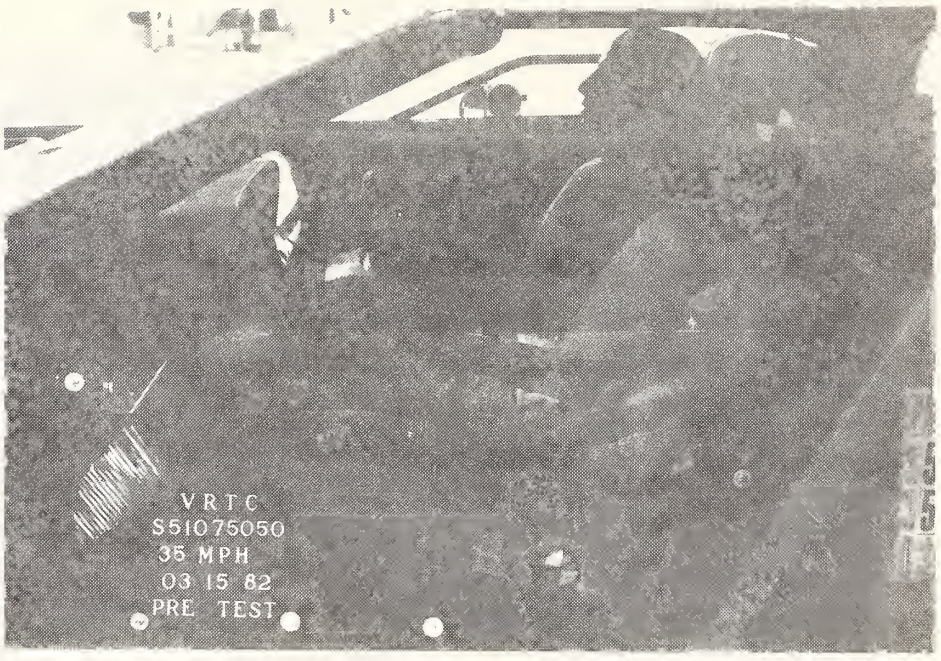


Figure 4-21A. Driver, Pre-Test

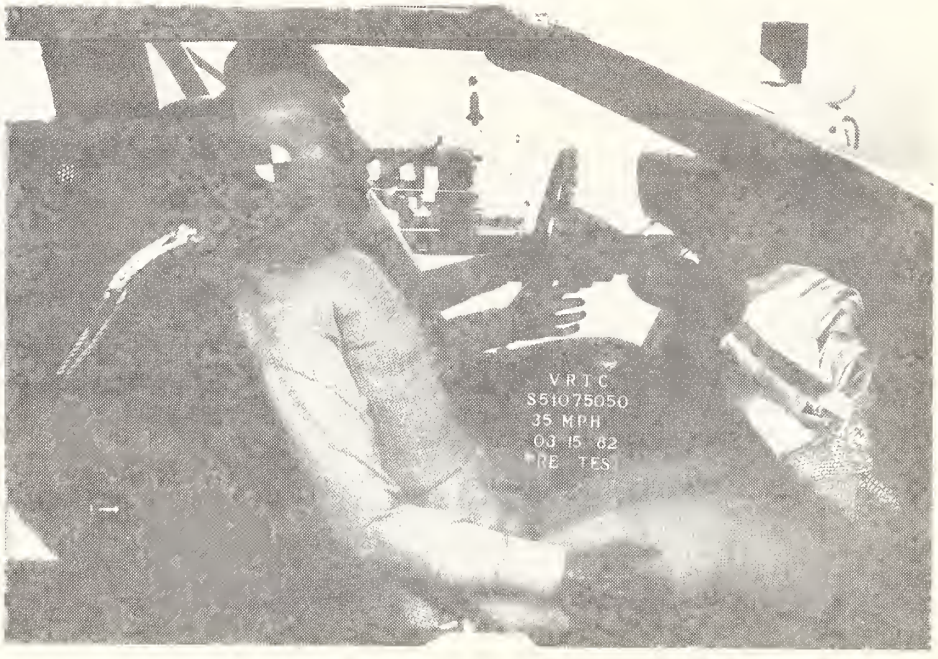


Figure 4-21B. Passenger, Pre-Test

d) added door on passenger side to confine airbag as it would be in actual vehicle.

e) moved passenger seat position one inch forward of mid seat position.

Figure 4-21B shows the passenger pre-test position.

Test Results

Driver: The chest injury measures were reduced significantly from Test No. 6 even though the restraint configuration remained the same. This lessening of the chest g's is attributed to the fact that the high speed movies showed the DeLorean column shroud completely rupturing in this test whereas in Test No. 6 it appeared to hold together and absorb additional load.

As shown in Table 4-1, the injury measures were well below the criteria limits presented in Table 1-1.

Figure 4-22 shows the driver post-test position. The steering column stroked 3 1/2 inches and the wheel crushed 2 1/8 inches for a total wheel/column crush of 5 5/8 inches.

Passenger: As a result of the changes made to the passenger system since Test No. 6, the injury measures were markedly reduced for this test. This reduction in injury measures is primarily attributed to the reduction in staging time from 17 msec in Test No. 6 to 7 msec in this test. This

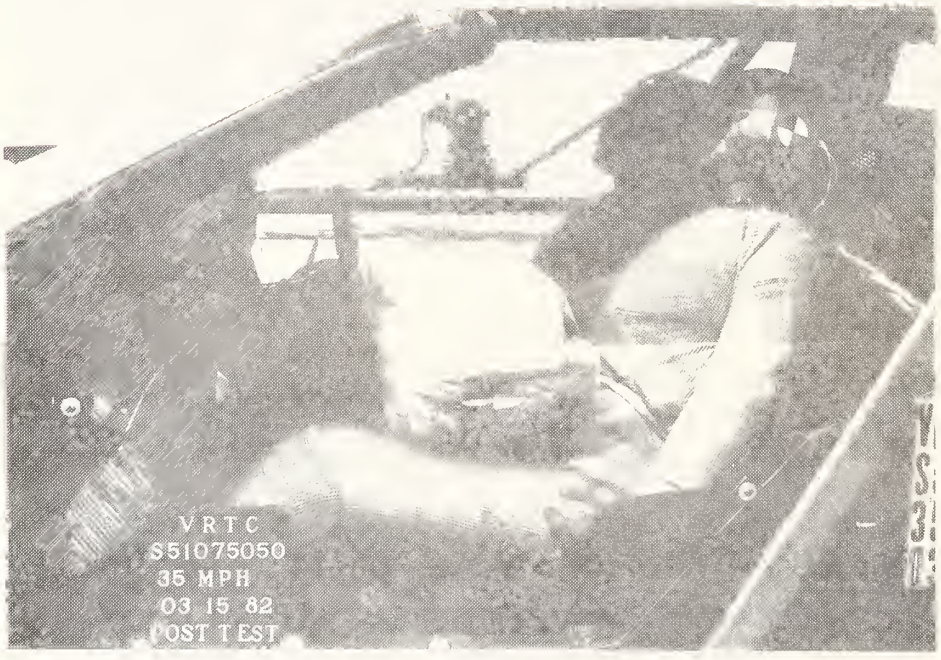


Figure 4-22. Driver, Post-Test

allowed the airbag to fill more rapidly so that a greater percentage of the passenger's kinetic energy could be absorbed in the stroke efficient ride-dowm mode.

This may be verified by comparing the airbag pressure traces from tests 6 and 7 in Appendix A. As may be seen from these traces, the airbag pressure reached a peak pressure of 6.5 psig at 97.5 msec in Test No. 6 whereas in this test it only reached 5 psig but did so more quickly, reaching a peak at 85 msec.

At this point in the sled test series we tentatively concluded that the passenger inflator staging time should be approximately 7 msec in order to obtain the optimum performance for the most common passenger configuration; i.e. the normally seated adult size range. We must, therefore, work out a satisfactory system for the less prevalent forward positioned child within this constraint of 7 msec staging time.

4.10 Test No. 8

Test Objective

Driver: To determine whether the driver restraint system which has evolved to this point will adequately protect (injury measures less than the criteria limits presented in Table 1-1) the 5th percentile female driver (the lower end of the potential driver size) at 35 mph impact velocity.

Passenger: To determine whether the restraint system configuration

that worked so well for the 50th percentile male at 35 mph would protect the 5th percentile female within the allowable injury criteria also.

Test Set-up

General: Test Velocity - 30 mph

Driver: Same as last test except 5th percentile female is being tested. The seat was moved forward 2 inches from the mid adjust position. Figure 4-23A shows the driver pre-test position.

Passenger: Same as last test except 5th percentile female is now being tested with the seat moved forward 3 inches from the mid adjust position. A new seat was also used. Figure 4-23B shows the passenger pre-test position.

Test Results

Driver: Again, as shown by Table 4-1, the injury measures for the driver were well within the injury criteria limits; however, relatively late in the impact event, the driver head was bent severely to the rear and the neck broke in two pieces at the junction of the rubber neck and the alumninum nut-plate (see Figure 4-24). It appeared that the mold bond broke on the tension side of this juncture and then spread across the neck during hyperextension. The smooth surface in the figure shows where the bond broke. Once this bond began to fail, the neck continued to separate until the opposite side was reached where it then tore the remaining rubber in tension.

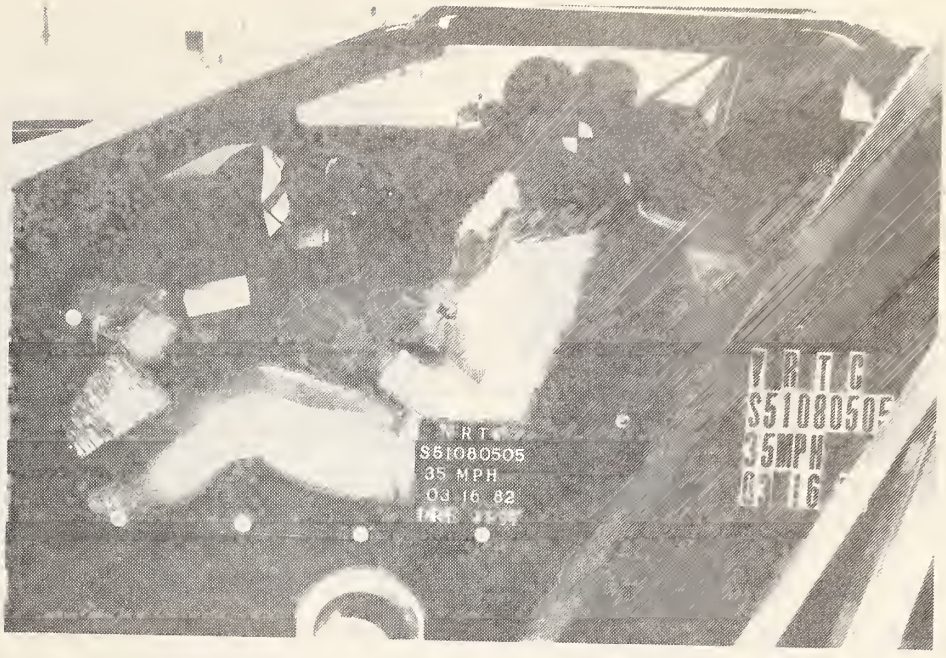


Figure 4-23A. Driver, Pre-Test

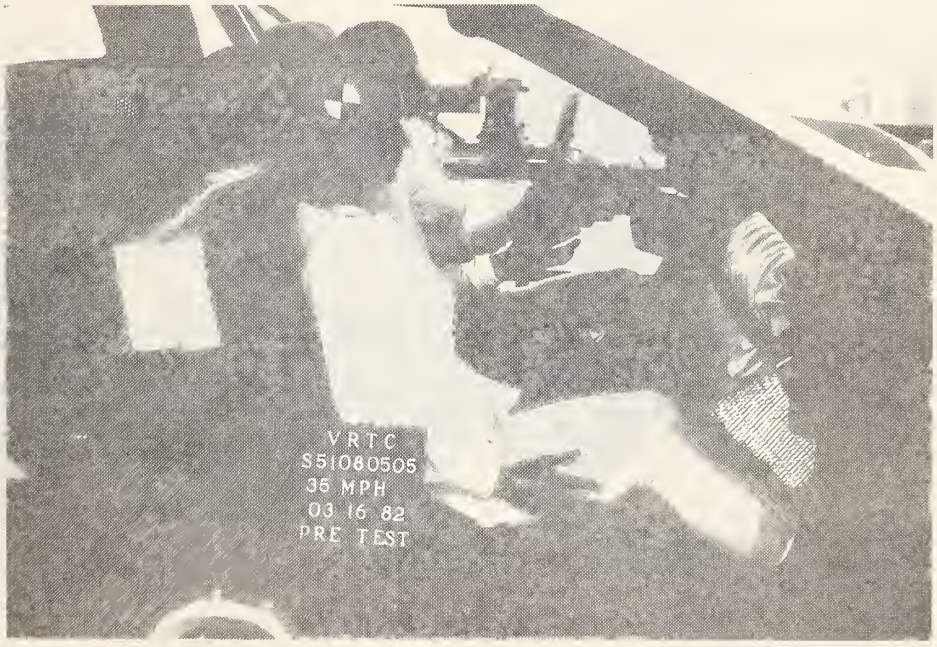
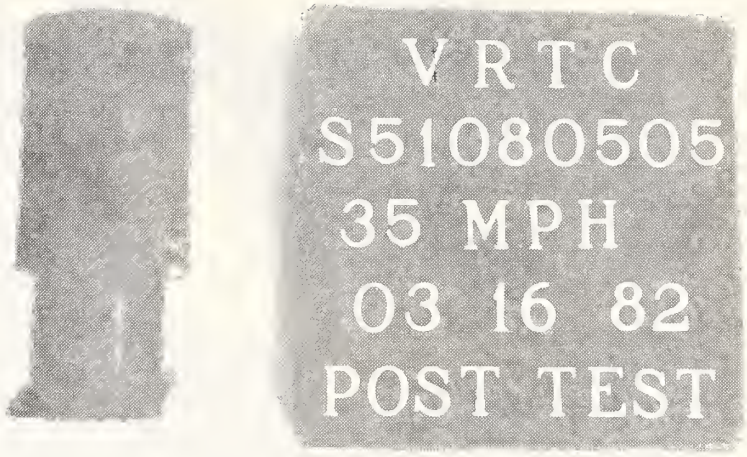


Figure 4-23B. Passenger, Pre-Test



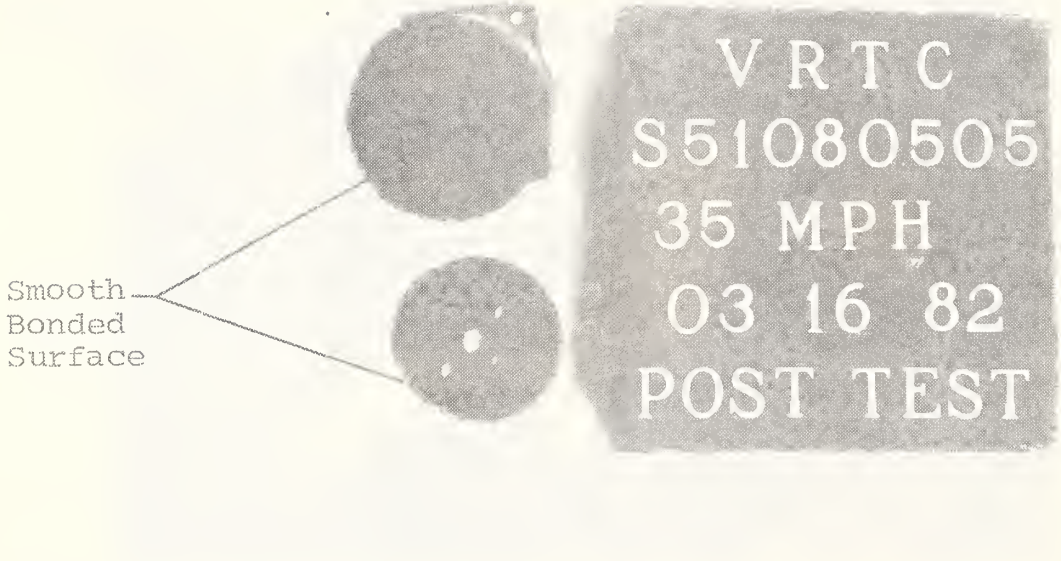


Figure 4-24. Driver Neck Fracture

Figure 4-25A shows the driver post-test position.

The column stroked 1 13/16 inches while the steering wheel crushed 5/8 inches for a combined stroke of 2 7/16 inches.

Passenger: Here too the injury measures were within specification indicating that the size range of potential passengers from 5th percentile female through 50th percentile male will be protected within the injury criteria limits at speeds up to at least 35 mph. Unfortunately, due to lack of headroom in the DeLorean compartment, the 95th percentile male could not be tested. However, for the reasons cited on pages 4-15 through 4-18, we believe the 95th percentile male could be tested in the actual vehicle without a head/header impact problem.

Figure 4-25B shows the passenger post-test position.

4.11 Test No. 9

Test Objective

Driver: To repeat Test No. 2 so as to obtain data "scatter" that exists from test-to-test when systems are made to reproduce each other as closely as possible.

Passenger: Passenger not tested due to lack of inflator hardware by test time.

Figure 4-25A. Driver, Post-Test

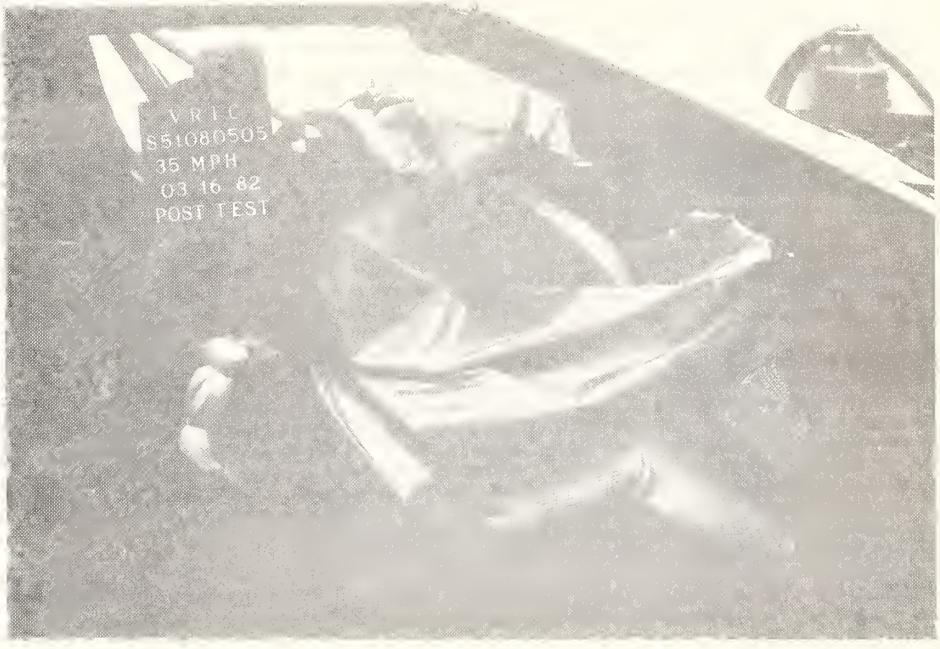


Figure 4-25B. Passenger, Post-Test

Test Set-up

General: Test Velocity - 30 mph

Driver: Same as last test except:

a) new 5th percentile driver neck

b) new seat

Figure 4-26 shows the pre-test driver position.

Passenger: Not tested.

Test Results

Driver: The table below compares the test results for this test with Test No. 2 which was set up in a very nearly identical fashion.

	Test No. 2	Test No. 9	Mean Value	% Deviation
HIC	214	203	208.5	+ & - 2.6%
Pk Res Cst G's(-3 ms)	33	39	36	+ & - 8.3%
Pk Femur Lds Avg,2 Femurs	1105#	1193#	1149#	+ & - 3.8%
Column Stroke	1 3/8"	1 5/16"	1 11/32"	+ & - 4.6%

In comparing the results of these two tests we see that

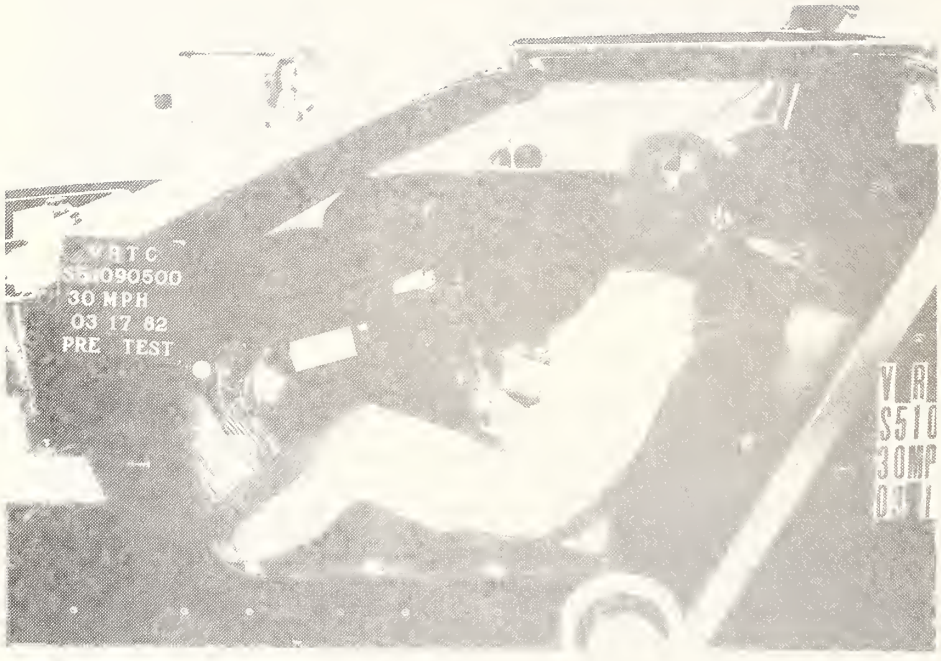


Figure 4-26. Driver, Pre-Test

the injury measures compare closely as far as HIC and femur loads are concerned, but the chest g's are 7 g's higher in Test No. 9. Looking at this on a percent basis, we see that the injury measure deviation is in the range of plus and minus 8 percent for the chest to approximately 3 percent for the HIC. Interestingly, this is the same approximate range (degree of data scatter) we found for the 50^{th} percentile male driver on page 4-39. We therefore conclude that computer simulations which attempt to duplicate a given test may not reasonably be expected to have less than approximately 8 to 10 percent deviation in the particular injury measure that exhibits the most "scatter" when test is compared to computer simulation. This is because, as stated on page 4-36, the computer simulation fidelity based upon a mathematical representation of a real event cannot be expected to be more accurate than the human ability to repetitively reproduce that event.

Again the injury measures were well below the criteria limits. Figure 4-27 shows the post-test driver position.

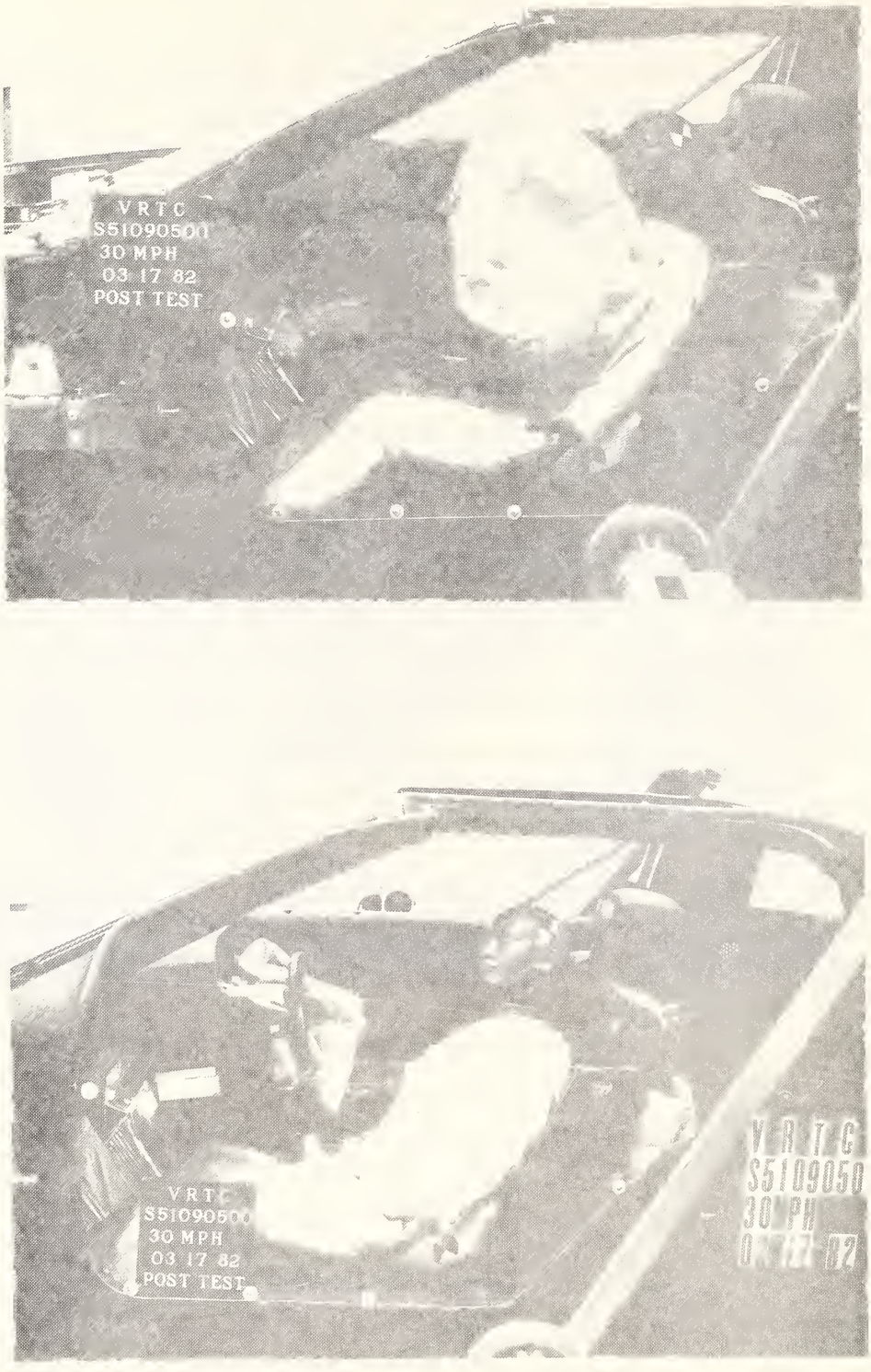


Figure 4-27. Driver, Post-Test Position

4.12 Test No. 10

Test Objective

Driver: To determine whether a ramped seat track which would raise small drivers as they moved the seat forward would reduce the overall injury measures and prevent any driver tendency toward "submarining".

Passenger: To determine the level of injury a 50th percentile male passenger would receive when protected with the passenger ACRS in a 30 mph crash.

Test Set-up

General: Test Velocity - 30 mph

Driver: Same as last test except the driver was boosted up in his seat by placing foam between the floor and underside of the seat. This resulted in an upward movement of the H-Point of 1 1/8 inches as compared to previous tests.

Figure 4-28A shows the driver pre-test position.

Passenger: Same as Test No. 8 except:

a) 50th percentile male (Fig. 4-28B shows pre-test photo)

b) Seat moved back to mid adjust position.

c) Seat modified by removal of some foam to cause passenger to sit slightly lower and not impact header.

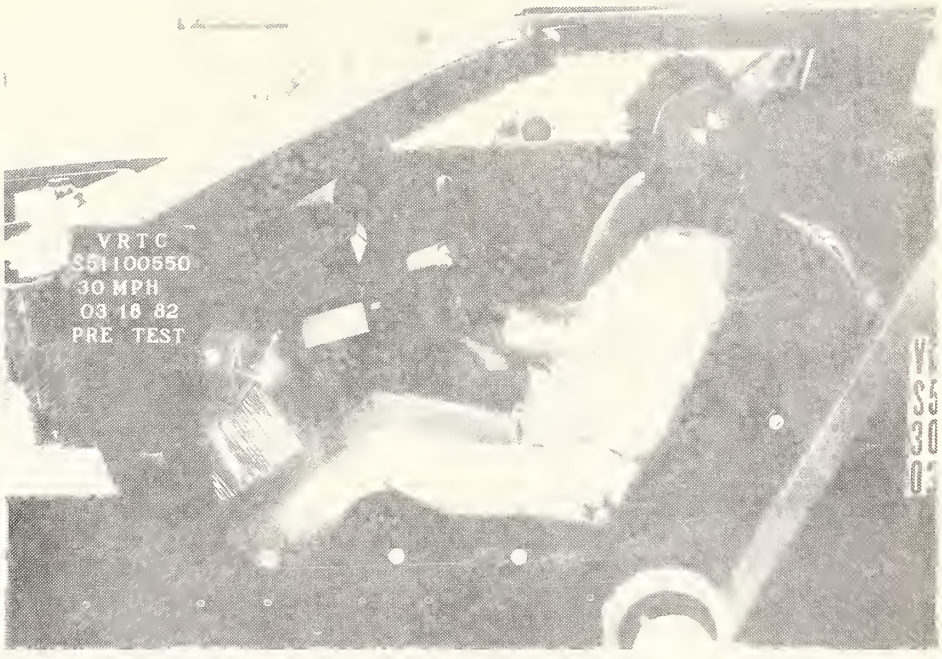


Figure 4-28A. Driver, Pre-Test

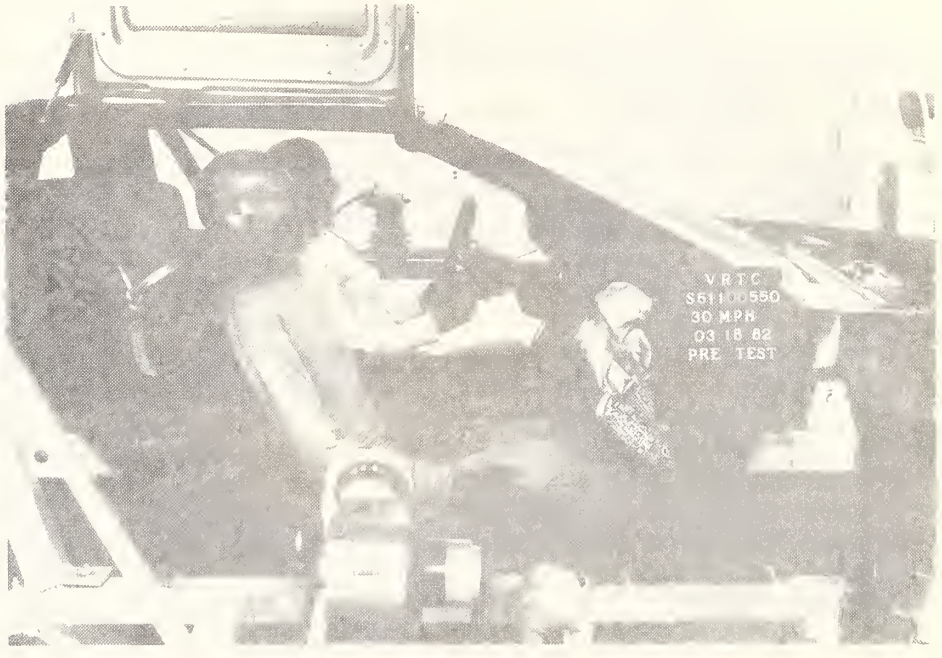


Figure 4-28B. Passenger, Pre-Test

Test Results

Driver: The injury measures were very low with a HIC of 147 and peak chest g's equal to 33 g (with 3 msec clip). Femur loads were 1260 and 1050 lb. for the left and right femurs respectively. Although this showed injury could possibly be reduced slightly by a "ramped" seat track, the injury measures were also very low in previously conducted tests without this modification. We therefore recommend that the seat track design be left unchanged.

The steering column stroked 1¼ inches and the steering wheel had too little crush to measure.

Throughout the sled test series the driver ACRS has shown itself to reliably protect the driver with injury measures very much below the criteria limits. We therefore recommend that the driver system design be "frozen" at the present configuration.

Figure 4-29A shows the driver post-test position. This was the final test conducted with the driver ACRS in this test series.

Passenger: The 50th percentile male passenger also received low injury measures. The HIC was 256 and peak chest g's (with 3 msec clip) was 39. Femur loads were 950 and 1020 lb. for the left and right femurs respectively.

Figure 4-29B shows the passenger post-test position.

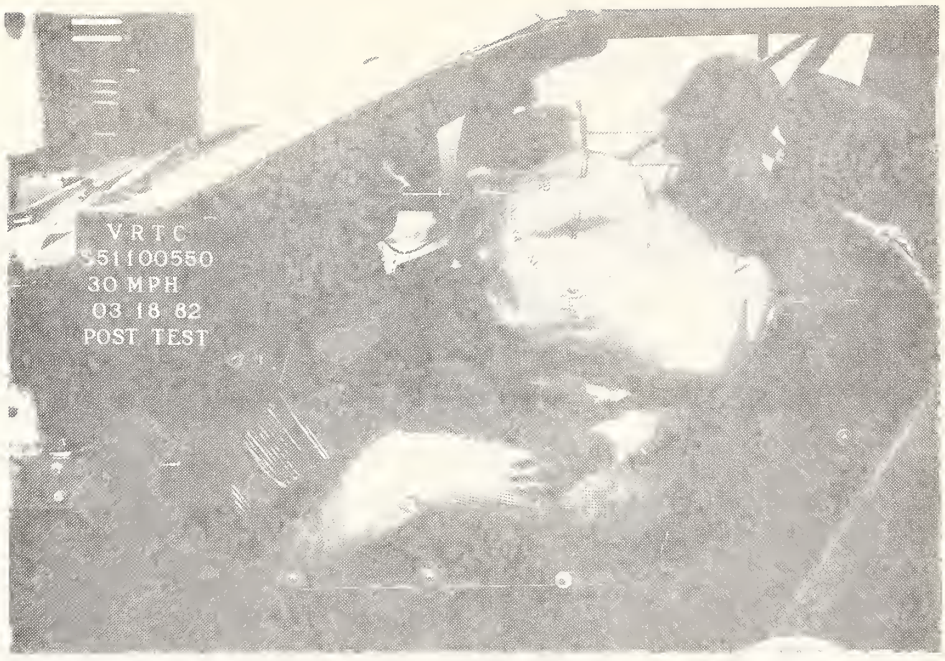


Figure 4-29A. Driver, Post-Test

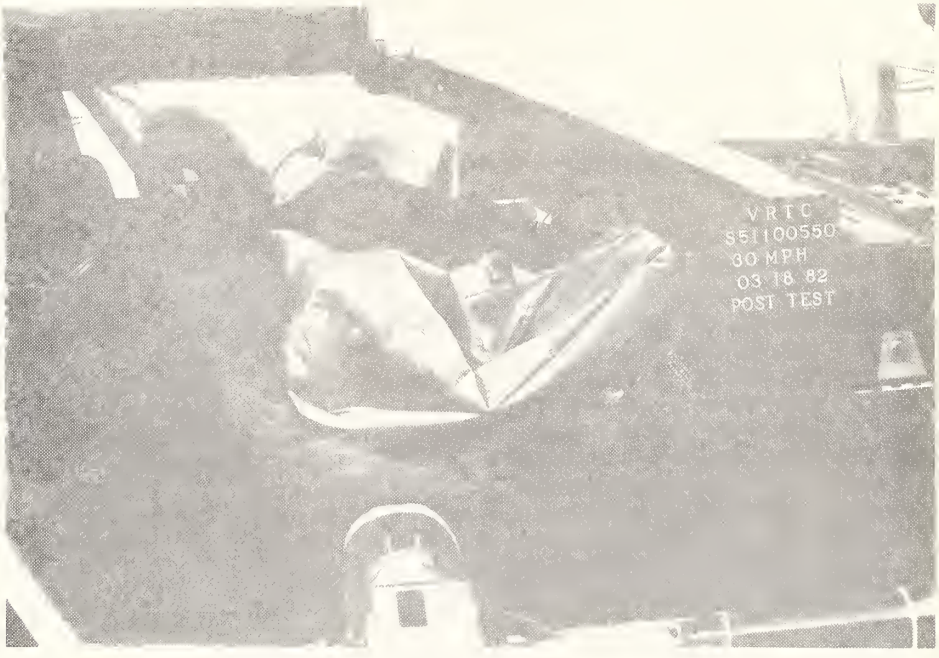


Figure 4-29B. Passenger, Post-Test

4.13 Test No. 11

Test Objective

Passenger: To determine whether the combination of 7 msec staging time, rolled under bag fold and a higher H-point location would produce injury measures within the criteria limits for the 3 yr old child seated in a forward position.

Test Set-up

General: Test Velocity - 30 mph

Passenger: The seat was moved to its rear-most position to allow more room for the bag to deploy downward after striking the child's chest. The chest-to-bag distance in the stowed configuration was 6 3/4 inches. The inflator staging time was 7 msec and the airbag was folded into the previously described "rolled under" configuration. The H-point was also raised approximately one and one-half inches. Figure 4-30 shows the child's pre-test position.

Test Results

Passenger: The child's injury measures were below the criteria limits as shown by Table 4-1. However the chest g's were just barely below the 60g limit at 59g's. Again, the test results were reasonably close to the pre-test computer simualtions as shown by the table on the following page. The results would have been closer had the input data in the simulations more closely matched the actual test conditions, but some of the input was only a "best guess" prior to actually conducting the tests.

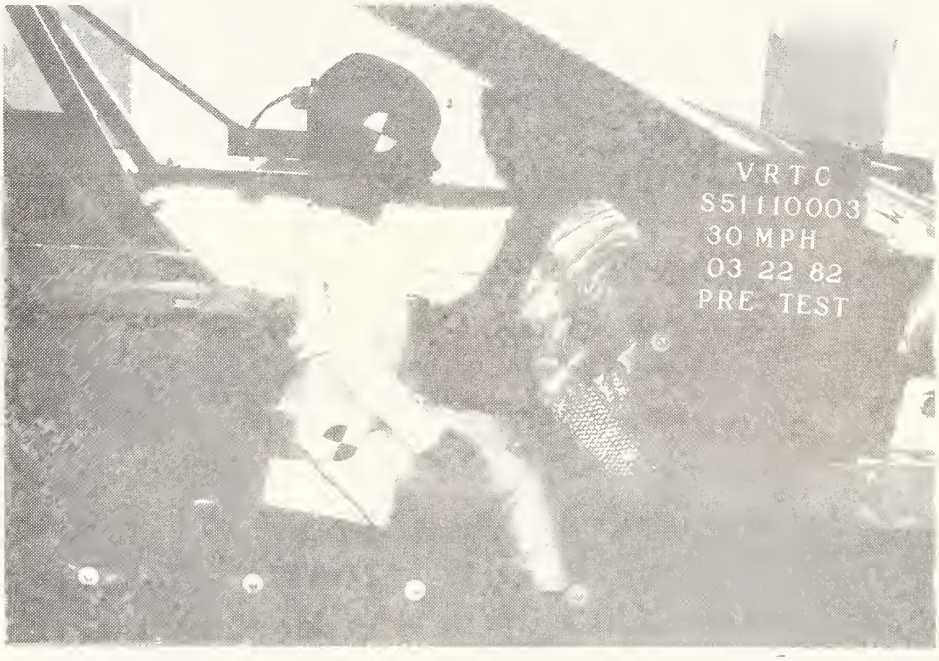


Figure 4-30. Passenger, Pre-Test

	Phase II Computer Simulation	Phase III Sled Test No. 11
HIC	1040	764
Pk Res Chest G's (-3 msec)	64	59

Figure 4-31 shows the child's post-test position.

4.14 Test No. 12

Test Objective

Passenger: To determine whether lowering the H-point 1.5 inches through seating the child directly on the seat (H-point not artificially raised as it was in preceding test) will adversely affect the child's degree of injury.

Test Set-up

General: Test Velocity - 30 mph

Passenger: Same as last test except child seated directly on seat (see Figure 4-32). This is the first test in which the child has been tested with the same set-up as sled tested successfully with the 5th percentile female and the 50th percentile male at 30 and 35 mph; i.e. with the "rolled under" bag fold and 7 msec inflator staging time with child seated on "stock" seat cushion.

Test Results

Passenger: The injury measures were almost identical to those

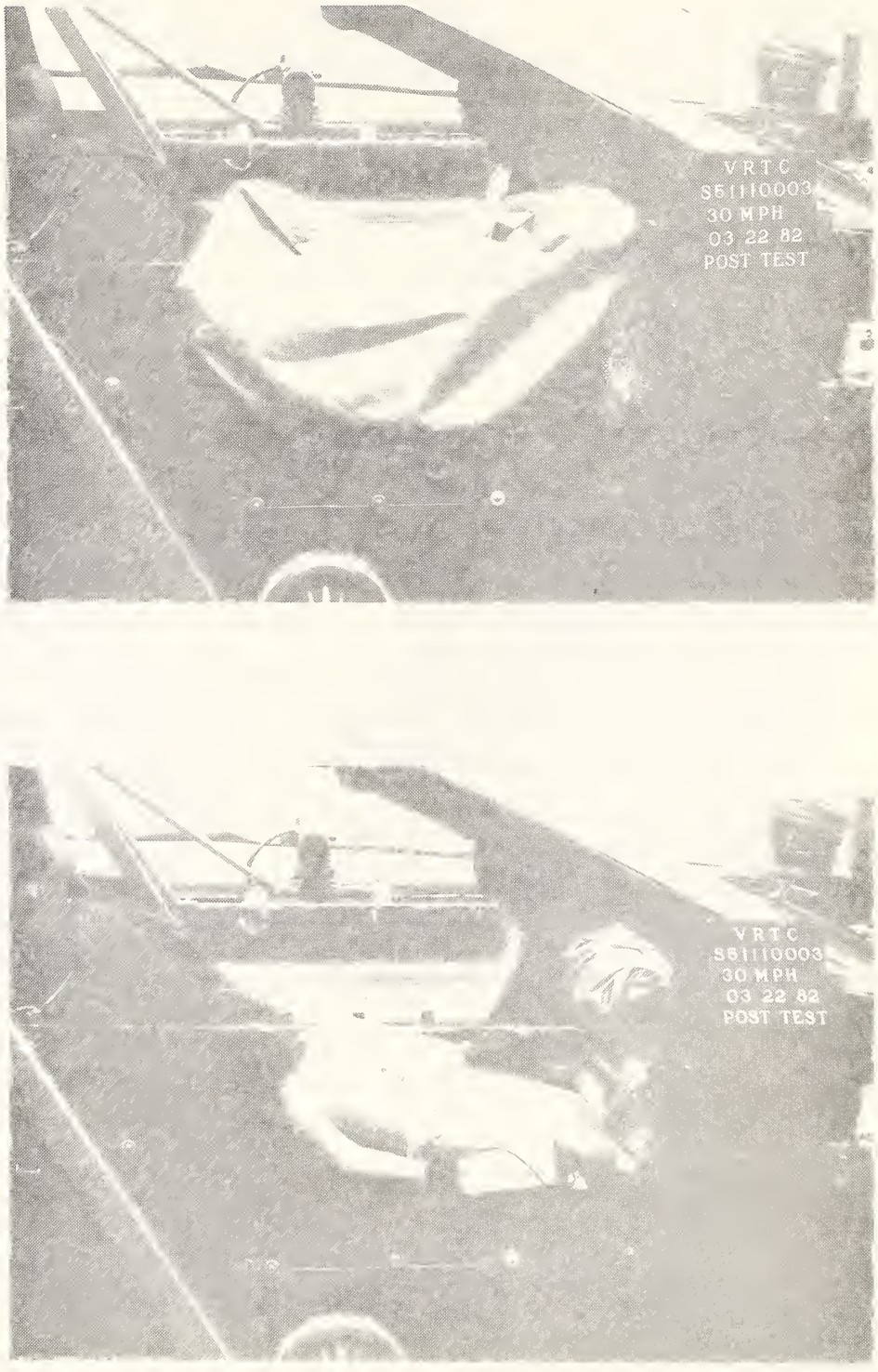


Figure 4-31. Passenger, Post-Test

Figure 4-32. Passenger, Pre-Test

received in the previous test. The HIC was 714 and the peak resultant chest g's were 59 g's (-3 msec). However, even though the chest g's were marginal in this and the preceding test, we believe the chest g's would have been lower had it not been for the 3 year old dummy chest construction. Just as we described a problem in obtaining a realistic representation for head g's on pages 4-19 through 4-21 (with appropriate back up information in Appendix B), so to a similar problem is encountered for the chest, albeit to a slightly lesser degree. The problem we believe is due to either the material used in the chest construction (a plastic type material) or in the construction of the accelerometer mount. Whatever the cause, a severe vibratory response it set up in the dummy chest and head when impacted by the airbag. As shown by the data presented in Appendix B, the problem is peculiar to the 3 year old dummy size.

Pages 295 through 298 and pages 313 through 316 show the dummy chest response for Tests 11 and 12 respectively. As can be seen, a definite vibratory response is present on all three chest axes just as it was for the head axes.

We therefore attribute the marginal chest g's to either the type of material and/or the accelerometer mount construction in the chest. Without these severe fluctuations in chest g response, the peak resultant g level would be reduced by approximately 9 g's (based upon drawing a line through the mid-point of these excursions.

We should also keep in mind that the chest g's received here are the highest that can be expected since we have

been testing at the computer selected "worst case" condition for the child which is seated, approximately 4-7 inches from the airbag at the time of vehicle impact and then impacted by the deploying airbag in a crash of at least 30 mph impact. For all other (and more probable) configurations with the child further from the dash, the injury measures are predicted to be lower; i.e. see Figures 4-5 and 4-6.

Figure 4-33 shows the post test position for the passenger.

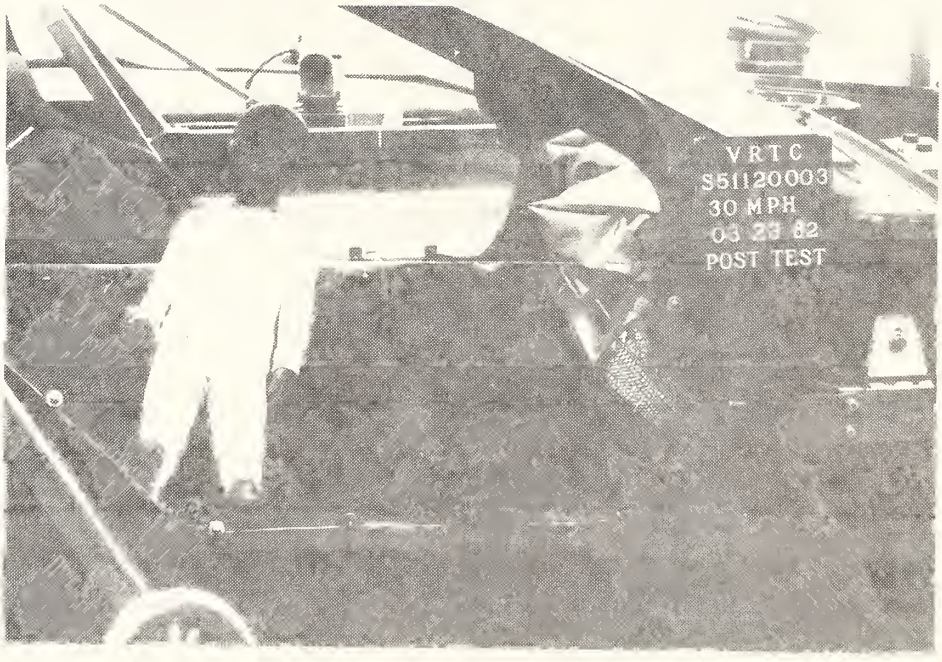


Figure 4-33. Passenger, Post-Test

5.0 POST-TEST COMPUTER SIMULATIONS

In this section of the final report we will be discussing the results of computer simulations which were run following the sled test phase. The purpose of these simulations was two-fold. First, we wanted to further validate the "PAC" computer model by using the DeLorean passenger restraint system and test results as a basis for comparison (the driver model, "DRACR", was being validated on a separate NHTSA program using these same sled test results). Second, we wanted to expand on what we learned in this test series. For example, due to the headroom problem for the 95th percentile male in the sled test environment (as described in Section 4.5 and pages 4-15 through 4-18), it was desirable to investigate the performance of the 95th percentile male in the actual DeLorean crash environment. This investigation could be done via computer simulation using the "PAC" model.

For these reasons, we scheduled a series of computer runs. In the following sections we will discuss the results of validating the "PAC" model using the 50th percentile male passenger and Sled Test No. 7 (a "typical" test in which nothing out of the ordinary occurred). Following this we will investigate the performance of the DeLorean restraint system in protecting the 95th percentile male in a 35 mph barrier crash. The crash pulse from the Phase I crash tests will be used as computer input.

5.1 "PAC" Model Validation

As discussed above, the test conditions for Sled Test No. 7 were duplicated on the computer and then a simulation of this test was made to further verify the fidelity of "PAC" to reproduce actual

test results. Figure 5-1 shows the sled test pulse and the data points used for input. Other data needed for input were obtained from pre-test measurements, known dummy properties and gas flow information provided by the gas generator manufacturer.

Figures 5-2 through 5-6 show the comparison of computer results and test results (Appendix C shows the actual computer run). As is evident from the figures, very good correlation was obtained.

Figure 5-7 shows the passenger trajectory as computed and plotted by the computer. Comparison of this trajectory with the results actually observed in the test show very similar dummy movement. The only difference that we noticed was that in the test the dummy H-point appeared to be approximately two inches lower than was measured before the test, perhaps due to seat compression. Thus the head is shown very close to the windshield in Figure 5-7; however in actuality it was not quite so close.

The table below compares the injury measures actually measured in the test with those predicted by the computer.

SLED TEST NO. 7

Injury Measure	Test Results	Computer Results
HIC	606	636
Pk. Res. Chest G's (-3 msec)	50	48
Pk. Femur Loads (Lb: Right, Left)	1070, 1140	1097, 1097

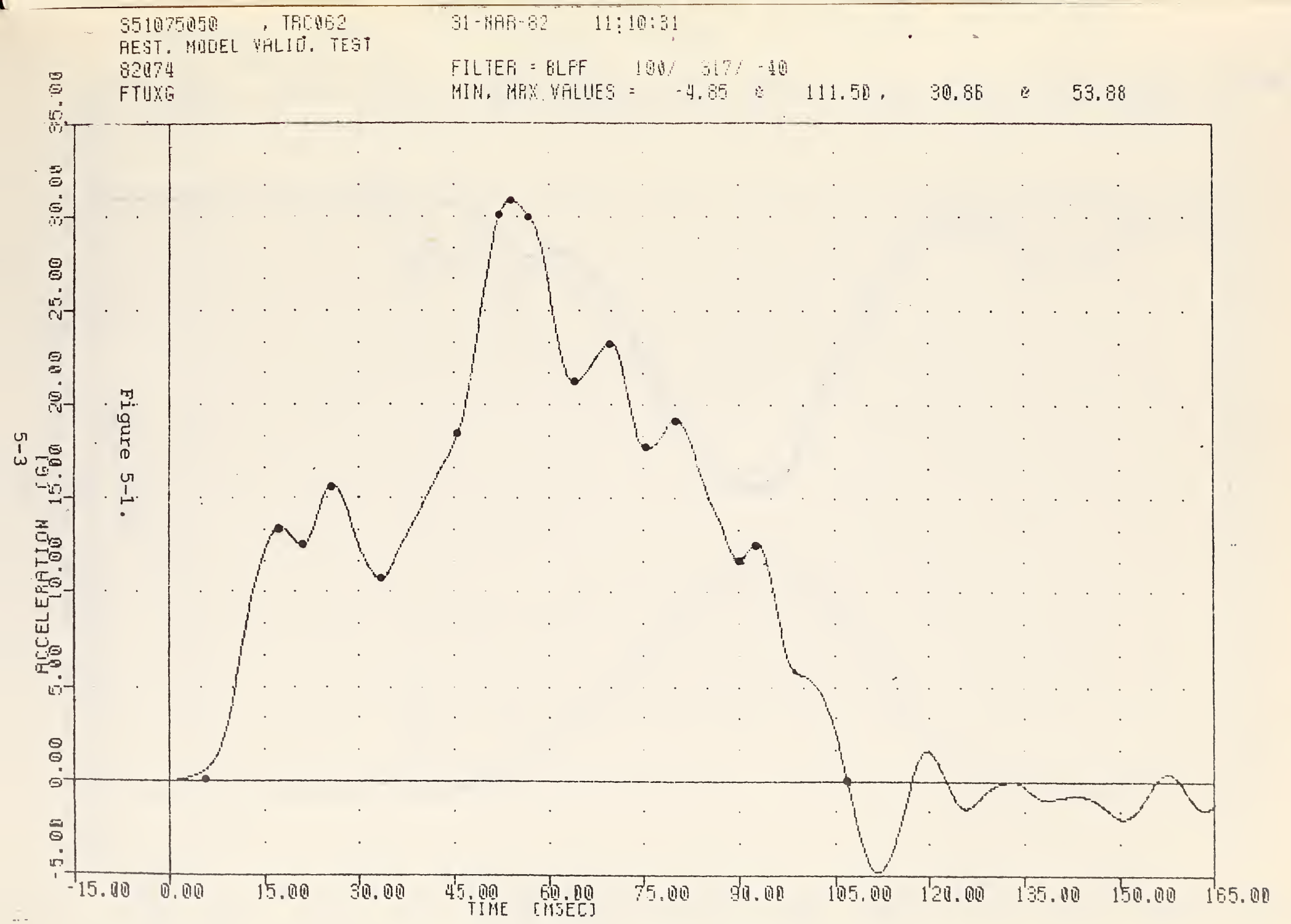
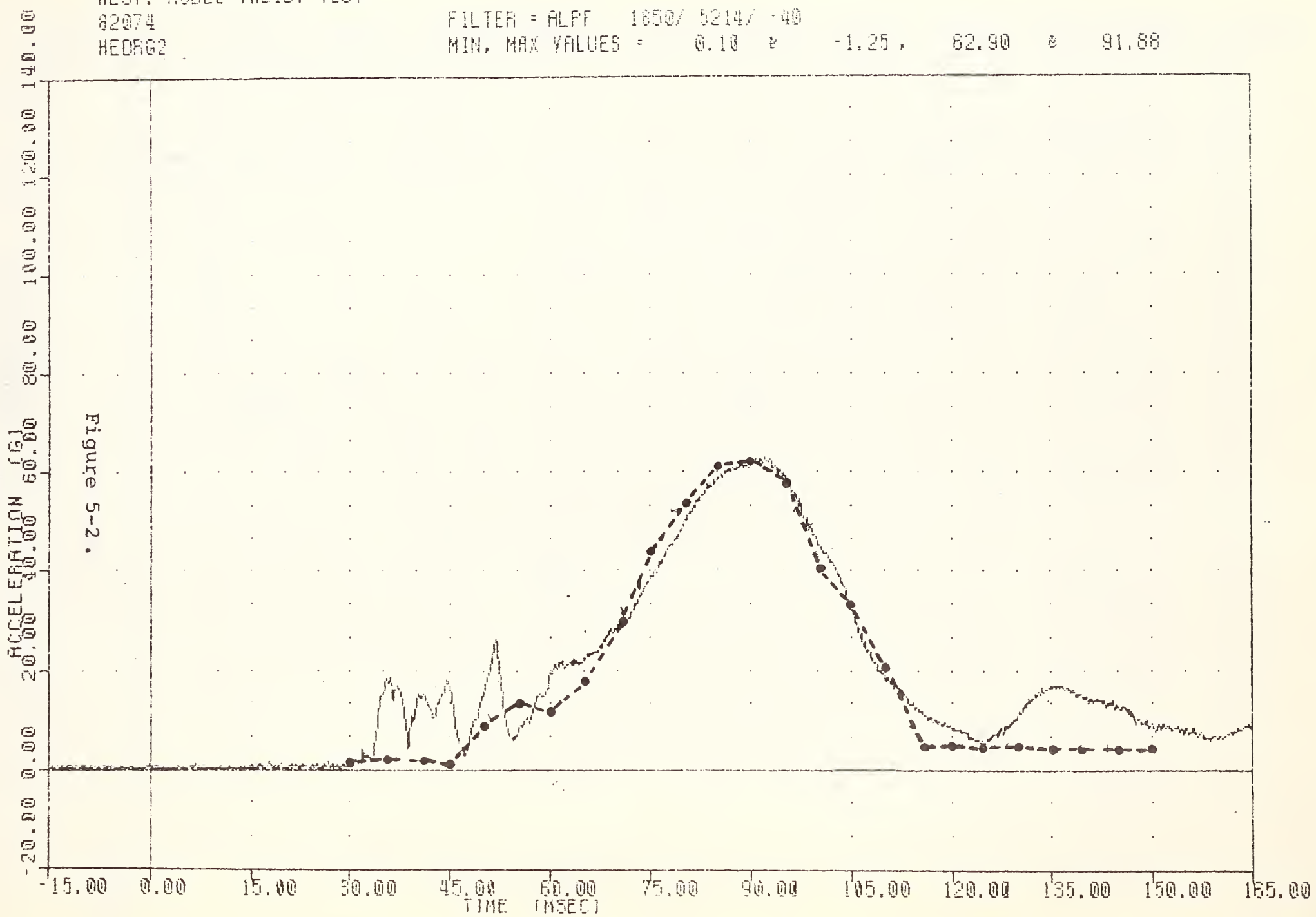


Figure 5-1.

FLOOR PAN TUNNEL ACCELERATION



HEAD ACCELERATION RESULTANT PASSENGER

S51075050 , TRC062 31-MAR-82 13:10:10
REST. MODEL VALID. TEST

Figure 5-2.

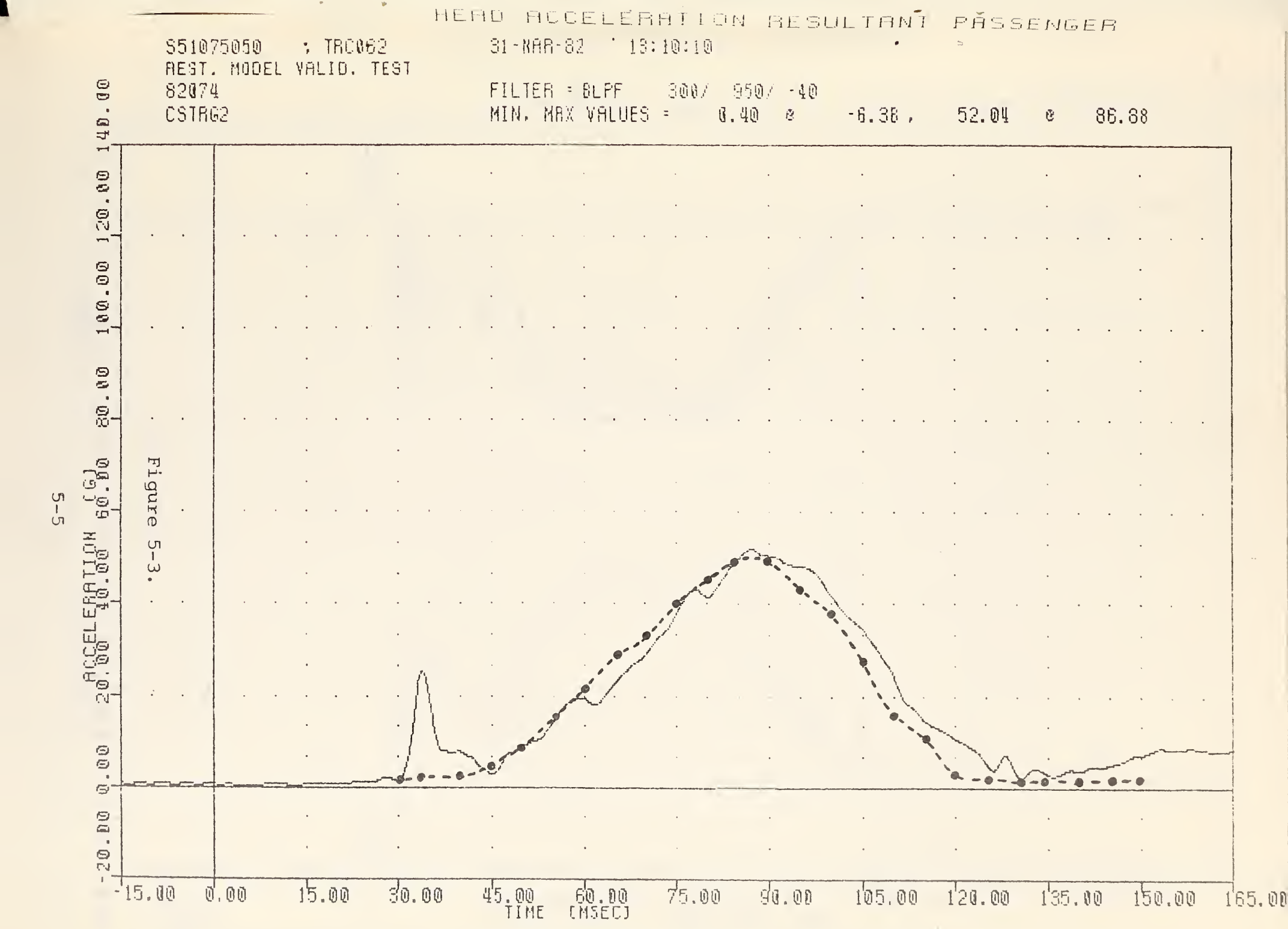

HEAD ACCELERATION RESULTANT PASSENGER
S51075050 ; TRC062 31-MAR-82 13:10:10
REST. MODEL VALID. TEST
82074
CSTRG2
FILTER = BLPF 300/ 950/ -40
MIN. MAX VALUES = 0.40 @ -6.38 , 52.04 @ 86.88
ACCELERATION (G)
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
-20.00
-15.00
0.00
15.00
30.00
45.00
60.00
75.00
90.00
105.00
120.00
135.00
150.00
165.00
TIME (MSEC)
CHEST ACCELERATION RESULTANT PASSENGER

Figure 5-3.

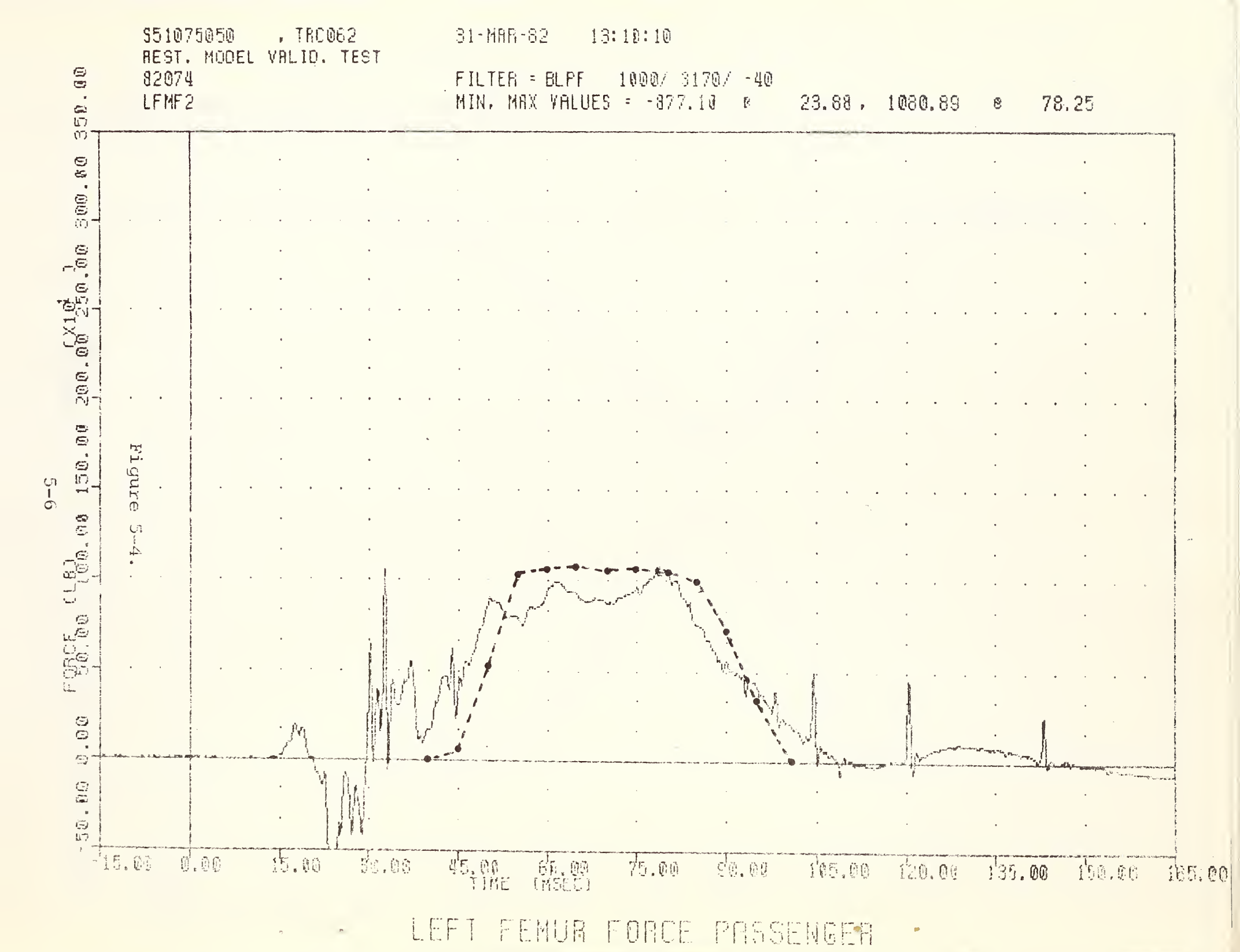


Figure 5-4.

LEFT FEMUR FORCE PASSENGER

S51075050 , TRC062
31-MAR-82 13:10:10
REST. MODEL VALID. TEST

LEFT FEMUR FORCE PASSENGER

S51075050 .. TRC062 31-MAR-82 13:10:10
REST. MODEL VALID. TEST
82074
RFNF2
FILTER = BLPF 1000/ 3170/ -40
MIN, MAX VALUES = -734.29 @ 23.75 , 1142.82 @ 62.00

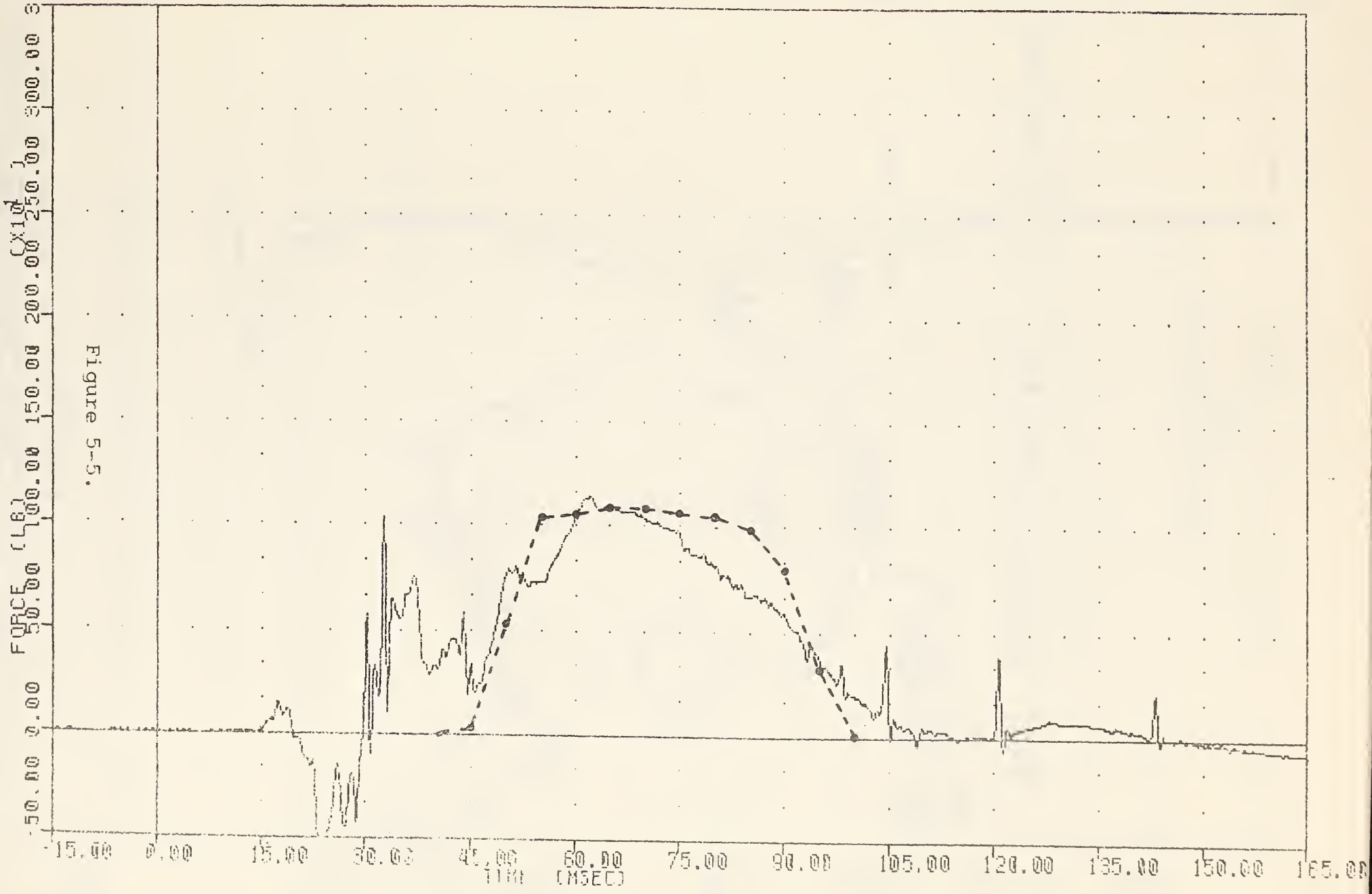


Figure 5-5.

RIGHT FEMUR FORCE PASSENGER

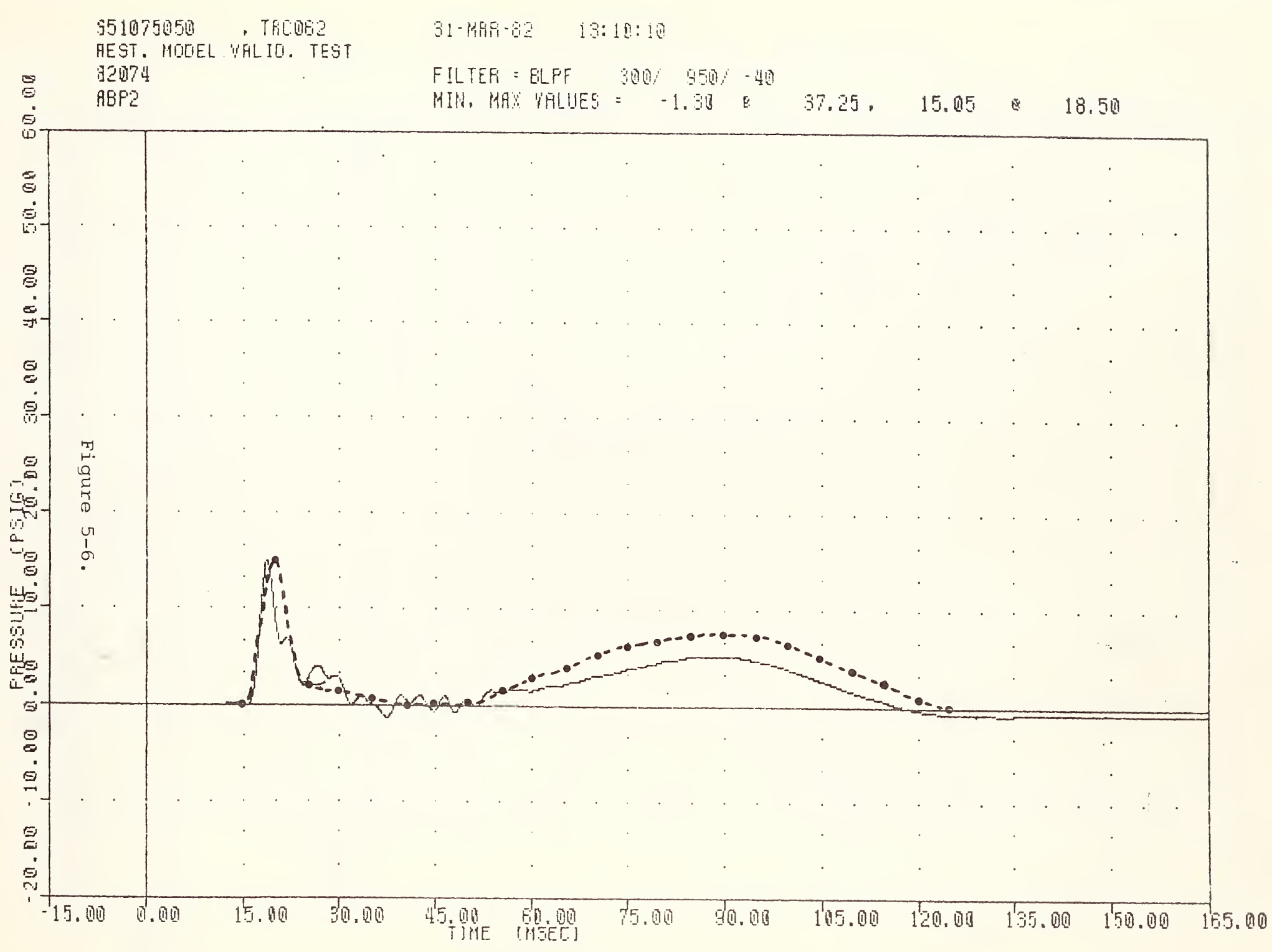


Figure 5-6.

AIR BAG PRESSURE PASSENGER

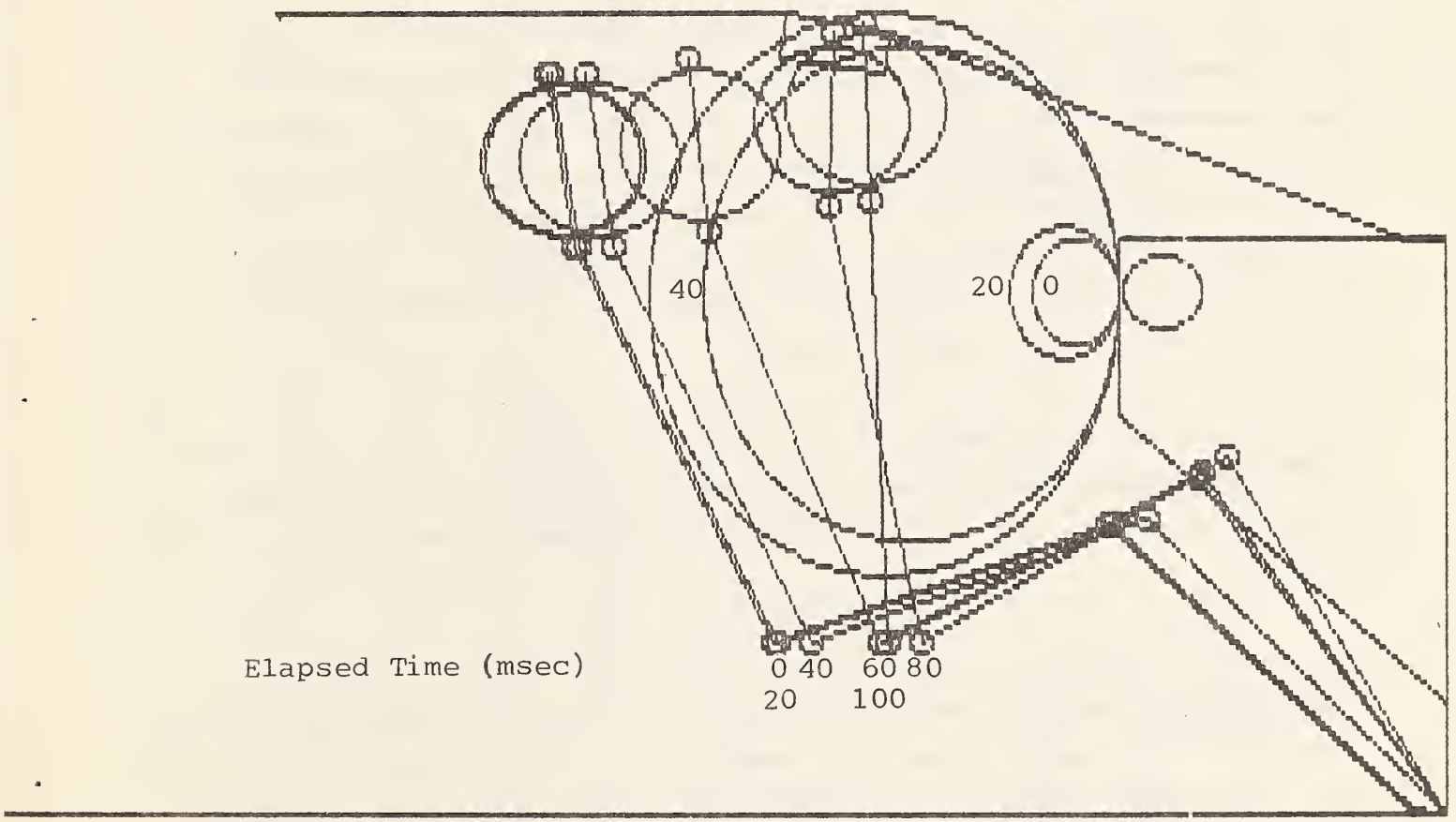
"PAC"

COMPUTER SIMULATION

OF:

DELOREAN SLED TEST NO. 7 - 50TH PERCENTILE PASSENGER - 34 MPH

HIC = 636
PK. CHEST G'S = 48 G'S
PK. FEMUR LOAD = 1097 LB



AIR BAG PRESSURE PASSENGER

Figure 5-7.

5.2 95th Percentile Male Simulations

Passenger

In order to determine whether the 95th percentile male's head would strike the header and/or windshield in an actual crash test in which the header rises during the crash as described on pages 4-15 to 4-18 and Fig. 5-8, "PAC" was run using the crash pulse from the Phase I Crash Test No. 1. Figures 5-9 and 5-10 show the results.

As shown by both figures, which differ only in the way the data is presented, the head is shown to clear both the windshield and the header. The height of the roofline used in the computer drawings was obtained by scaling the high speed movies of the crash. In addition the H-Point was lowered to account for the collapse of the floor pan in the crash - again by the amount deemed correct based upon movie analysis. Injury measures predicted by "PAC" are also presented.

Based upon this analysis we conclude that in an actual crash the 95th percentile dummy head would not strike the windshield or header. Further, his injury measures would be below the criteria limits.

Just for further information, we re-ran the computer schematic drawing for the case where the roof-line was not raised (as in the sled test series) and the dummy was seated on the floor of the sled buck. Figure 5-11 shows this case. Two things are readily apparent. First the head will strike the header and/or windshield. Second, the dummy head position is very much the same as shown by Figure 4-34 which is an actual photograph of the 95th percentile male dummy seated on the floor of the DeLorean sled buck and pushed forward until his head contacts the header.

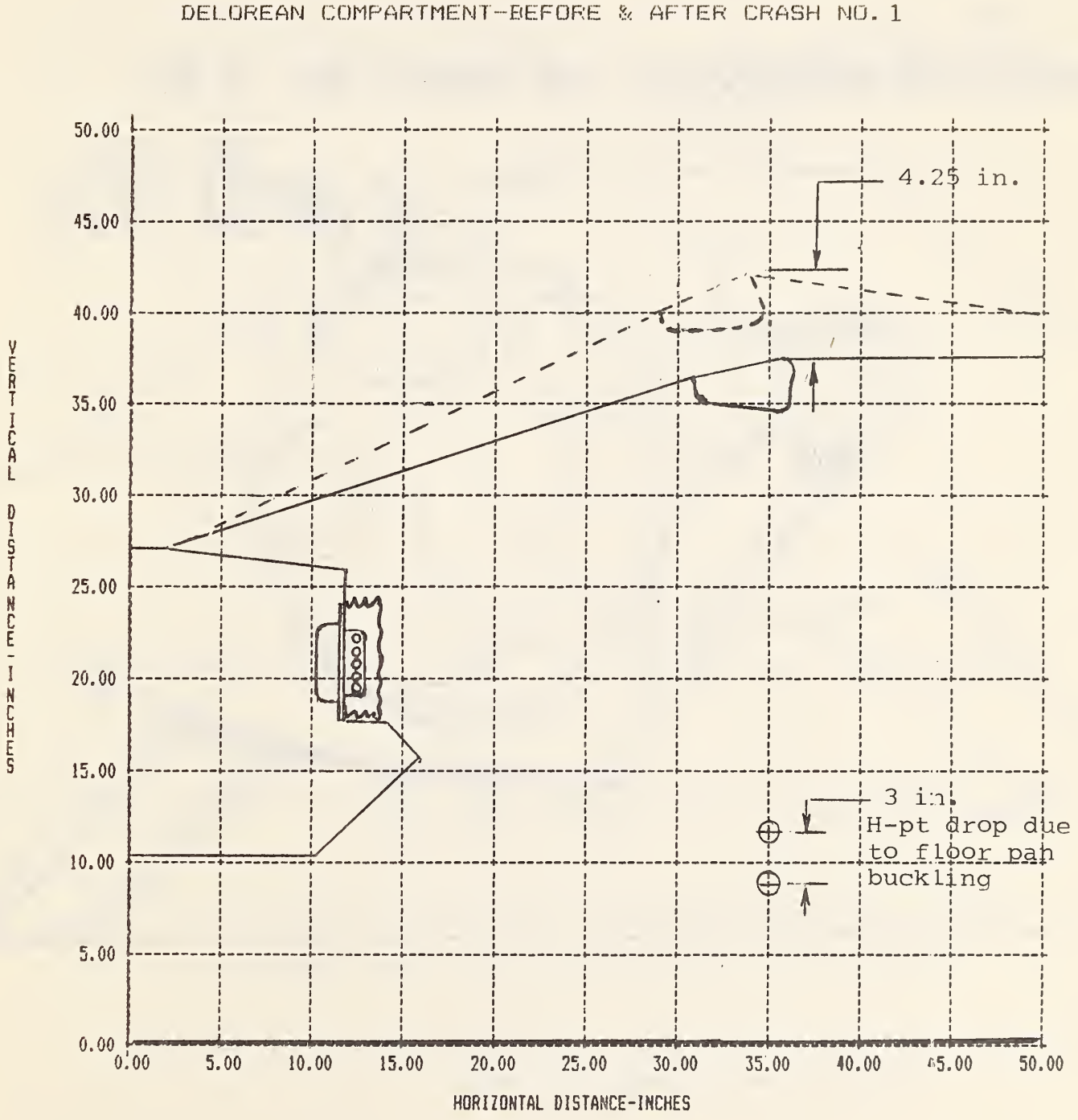


Figure 5-8. DeLorean Compartment Pre and Post Test

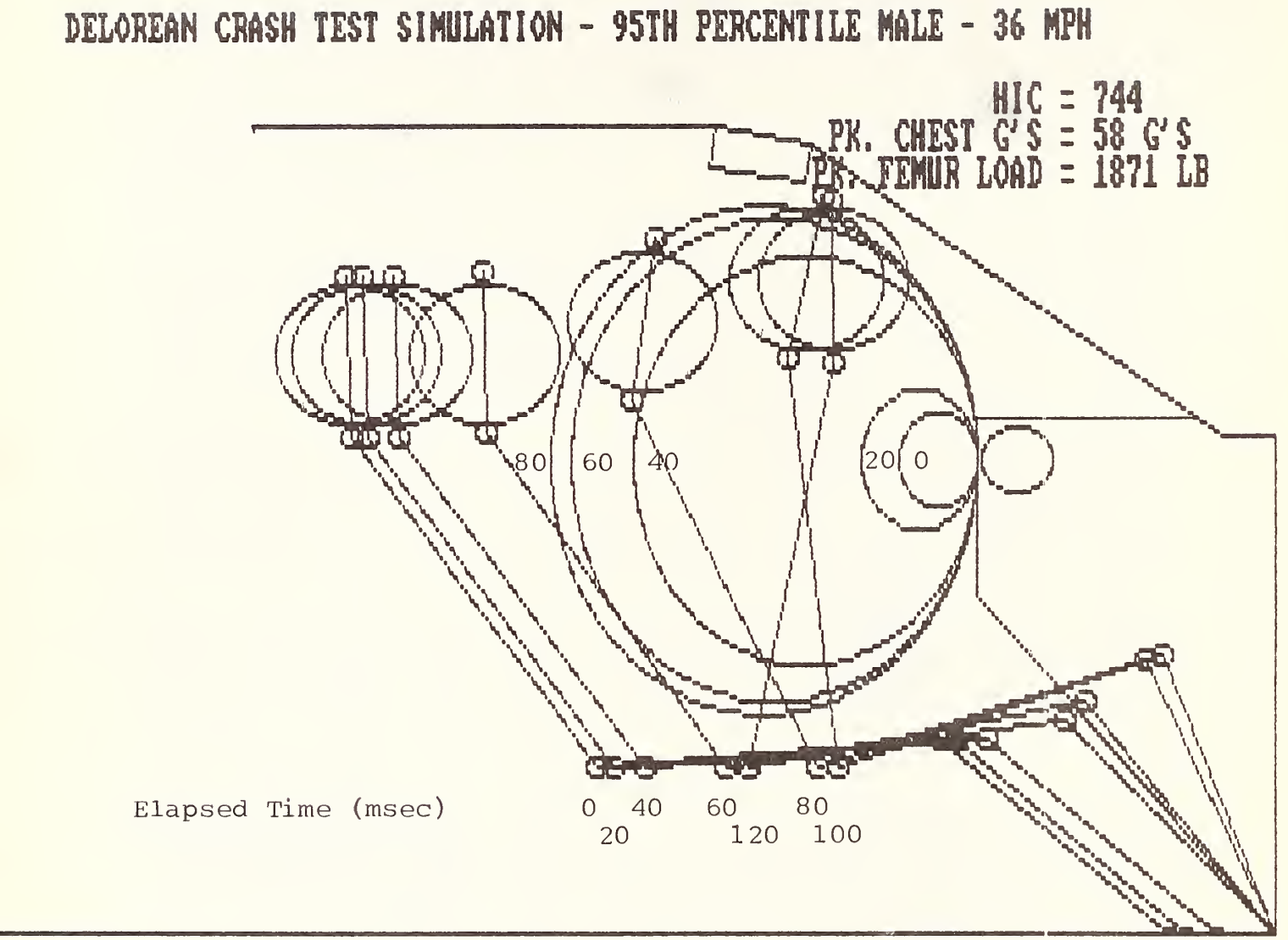


Figure 5-9. Passenger Trajectory - Roofline Raised Due to Crash
(Position shown every 20 msec)

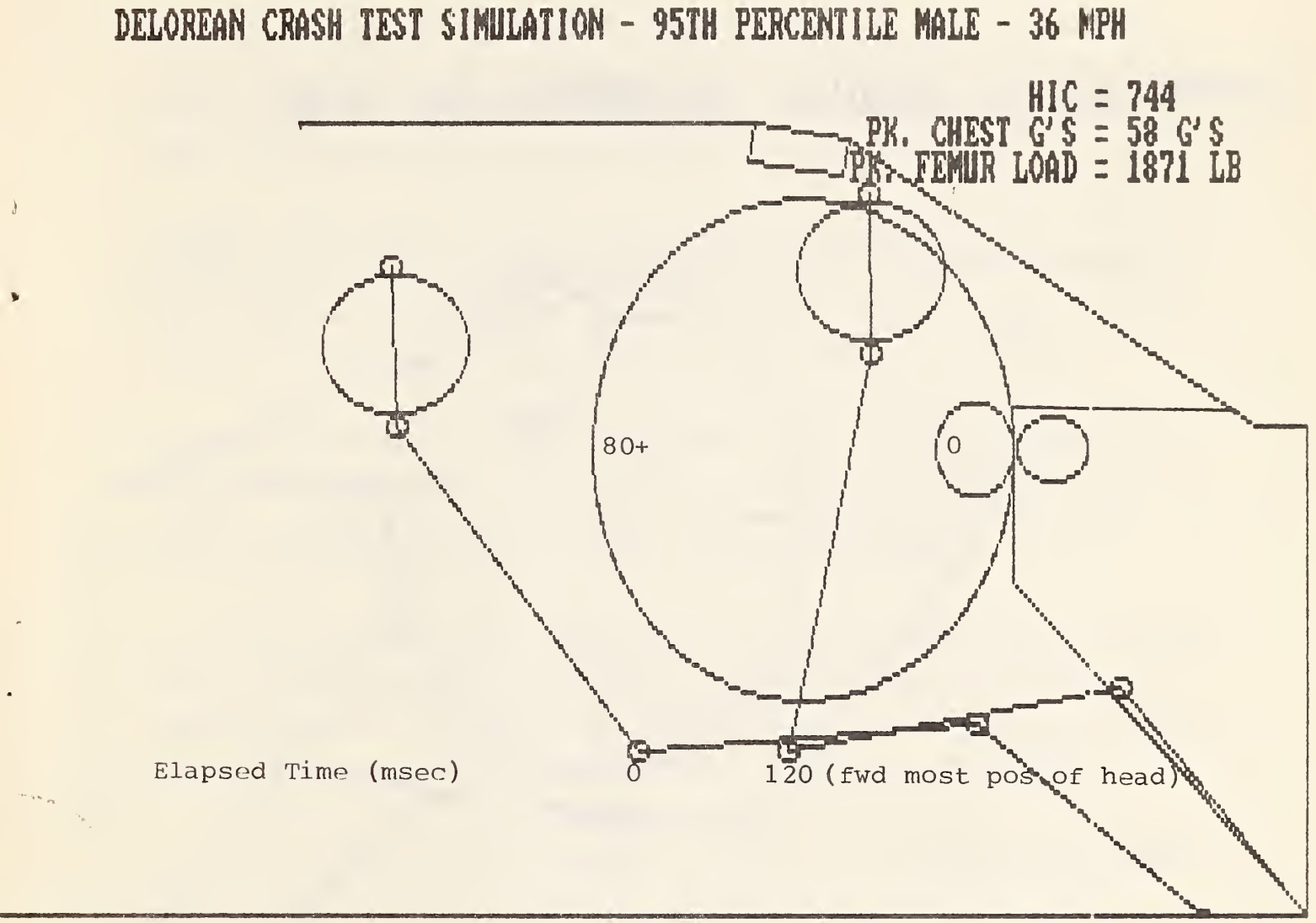

DELOREAN CRASH TEST SIMULATION - 95TH PERCENTILE MALE - 36 MPH
HIC = 744
PK. CHEST G'S = 58 G'S
PK. FEMUR LOAD = 1871 LB
80+
0
Elapsed Time (msec)
0
120 (fwd most pos of head)

Figure 5-10. Passenger Trajectory - Roofline Raised Due to Crash (Original and Most Forward Head Position Shown)

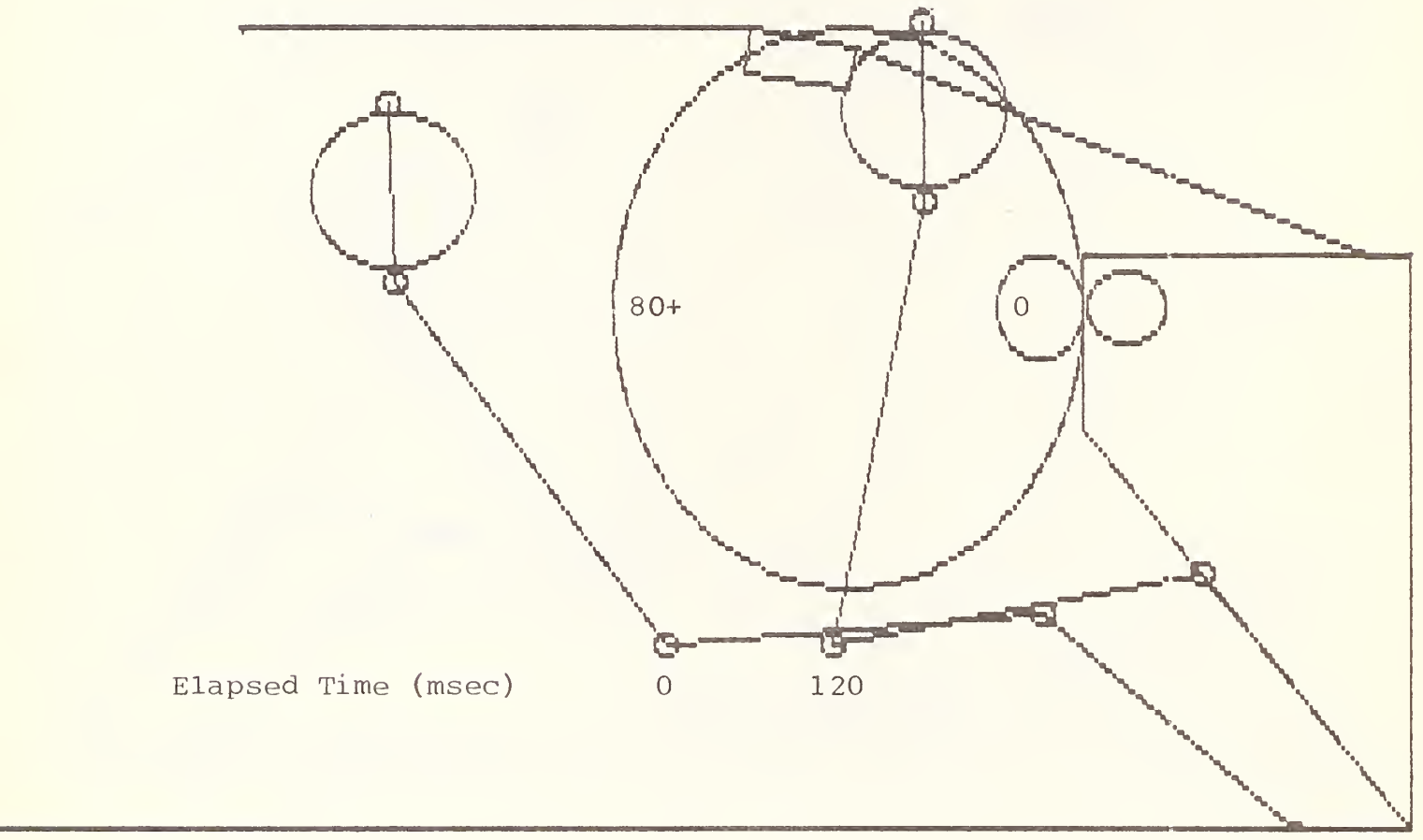


Figure 5-11. Passenger Trajectory - Roofline Not Raised (Sled Tests)
(Original and Most Forward Head Position Shown)

Driver

Just as we ran a few computer simulations for the passenger to determine whether the head would contact the header and/or windshield under actual crash conditions, we also made a few computer runs for the driver for similar reasons.

*Figures 5-12 and 5-13 show the predicted trajectory for the 95th percentile male using the "DRACR" computer program. As shown by both figures, which differ only in the way the data is presented, the head misses both the windshield and header.

Based upon this analysis we conclude that in an actual crash the 95th percentile dummy head would not strike the windshield or header. In addition, his injury measures should be well below the injury criteria limits up to at least 36 mph.

We re-ran the computer schematic for the case where the roof-line did not raise during the crash (as in the sled tests) with the dummy seated on the floor (no seat). Figure 5-14 shows the results for this case. Here we see the head does impact the header.

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*Please note that the figures are to scale showing the column crush and rotation plus the wheel crush and rotation with respect to the column.

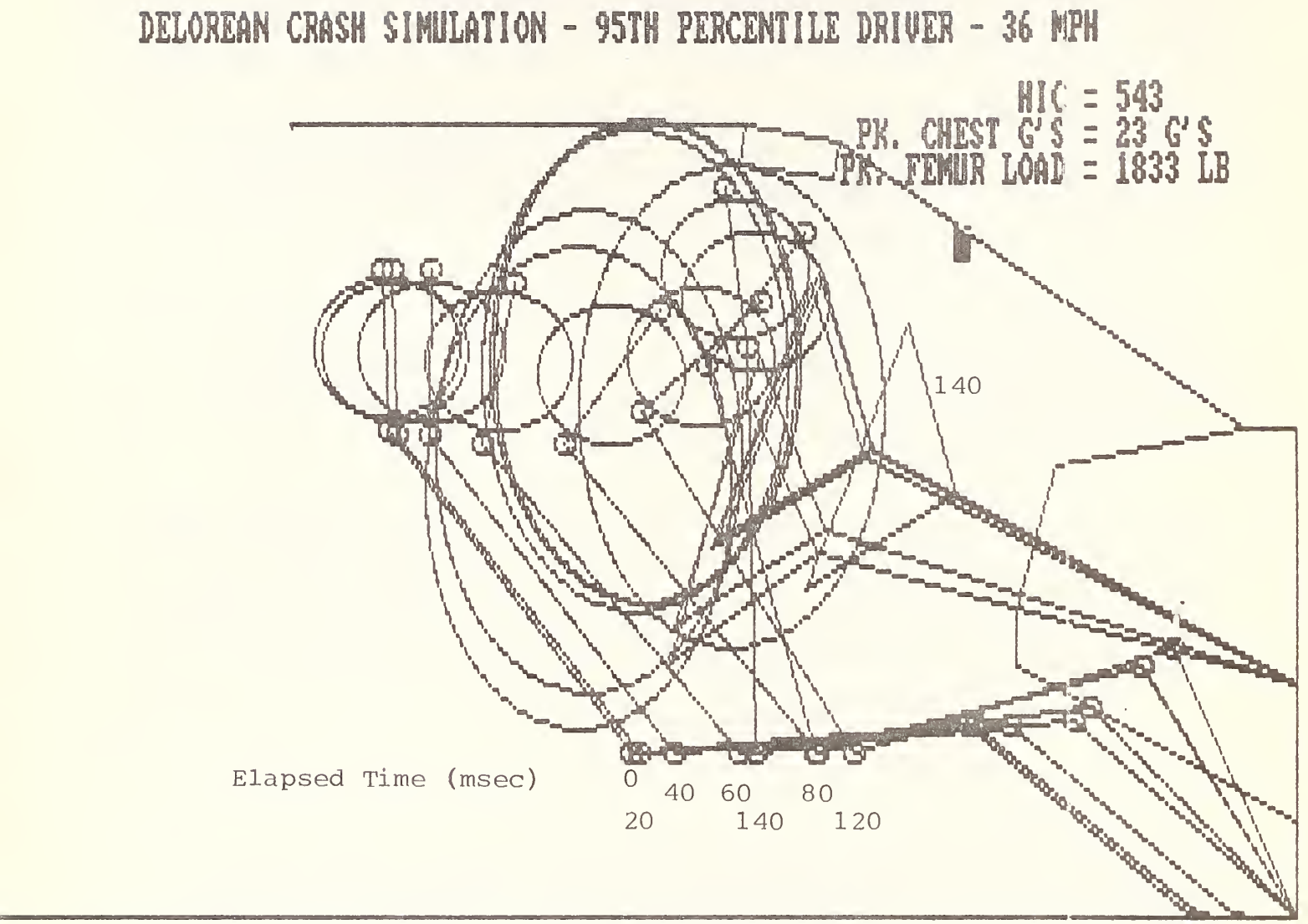

Figure 5-12. Driver Trajectory - Roofline Raised Due to Crash (Position shown every 20 msec)

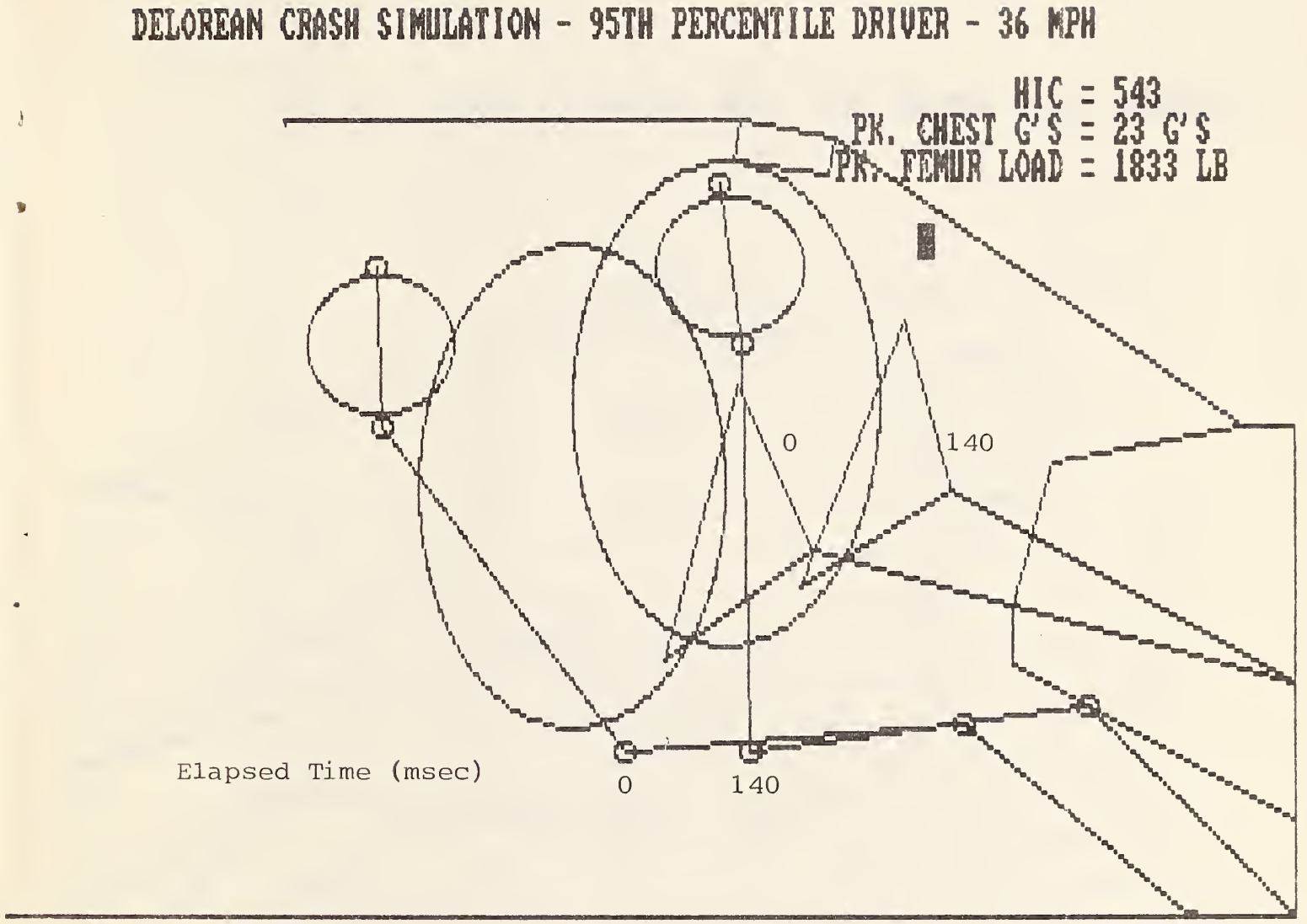

Figure 5-13. Driver Trajectory - Roofline Raised Due to Crash (Original and Most Forward Head Position Shown)

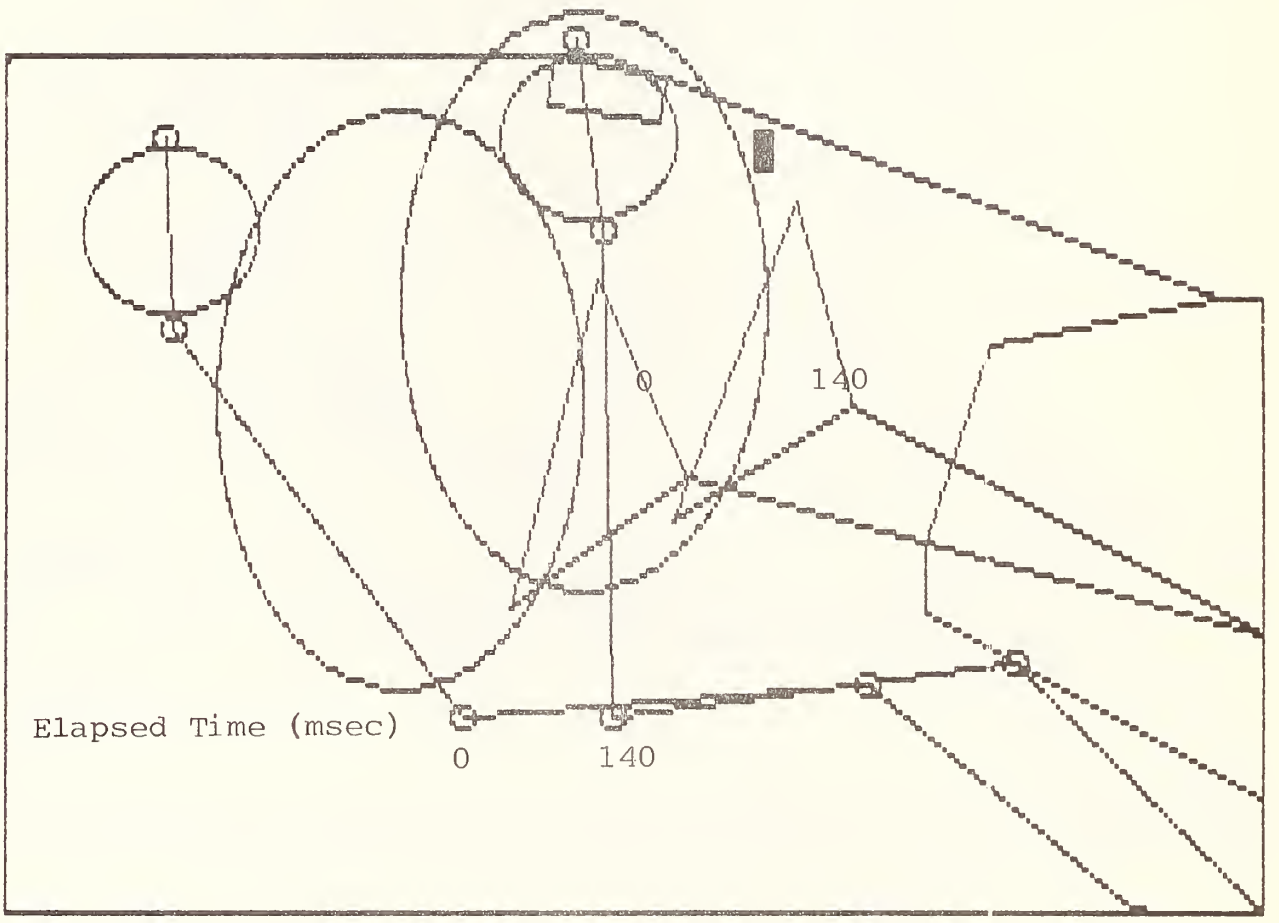

Figure 5-14. Driver Trajectory - Roofline Not Raised (Sled Tests)
(Original and Most Forward Head Position Shown)

6.0 Conclusions and Recommendations

During the course of this program we arrived at several conclusions which, in turn, led to our making certain recommendations. In the following paragraphs we will enumerate each.

Conclusions

1. The driver and passenger air cushion designs with which we ended the Phase III sled test series is surprisingly close to the designs used in the Phase I crash tests.

   These early driver and passenger system designs which were derived via computer simulation of the DeLorean crash environment during the Phase I analysis changed very little throughout the Phase II computer "tuning" analysis and the Phase III sled testing. For example, for both the driver and passenger systems the airbag designs, the airbag vent areas, the inflator staging time, the knee restraint design and the method of integrating the restraint systems into the DeLorean has remained unchanged through these many months. That is not to say that modifications to these basic designs were not evaluated through testing because they were; however in all cases except one, we returned to our original choice.

   The lone change[1] made to the design was made during this sled test phase. This change was made to the passenger system and was to fold the airbag differently. The original "accordian" fold which resulted in a rather high airbag deployment and concomitantly high head injury measures for the forward positioned child was replaced by a 'rolled under" bag fold which caused the bag to deploy lower with a correspondingly lower HIC.

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[1] Please see footnote on page 6-7.

2. The Phase III sled tests demonstrated the present air cushion design for the driver is able to protect the size range of potential drivers from 5th percentile female through (at least) the 50th percentile male at frontal impact velocities of at least 35 mph (the maximum velocity tested in the sled tests) with injury measures substantially below the criteria limits.

The Phase I vehicle crashes with the 50th percentile male driver ATD showed that the impact velocity may be increased beyond 40 mph in a frontal crash and the driver will still receive injury measures well below the criteria limits. We believe this would probably be the case for the 5th percentile female also if tested at these speeds. The basis for this statement is the relatively low injury measures received at 35 mph and the availability of more stroking room in the DeLorean compartment.

We are unable to draw any conclusions based upon test results for the 95th percentile male driver as this driver size was not tested in the Phase I vehicle crashes and we were unable to prevent the head from striking the header in the sled tests. Figure 4-34, which shows the 95th percentile male seated in the DeLorean compartment with the seat removed so that the buttocks rest on the compartment floor, shows why. The head of the 95th percentile male, even when sitting on the floor, is higher than the roof line of the DeLorean. In spite of this fact, however, we predict that, based upon the computer results presented in Section 5.2 of this report, the 95th percentile male's head would not impact the header in an actual vehicle

Figure 4-34. 95th Percentile Male ATD Seated on Floor of DeLorean Compartment.

crash. We would recommend that NHTSA verify this fact as well as demonstrate that the injury measures of the 95th percentile male would be below criteria limits by conducting a single vehicle crash at 35 mph with the driver and passenger positions occupied by 95th percentile male ATD's. Such a vehicle is available at the Vehicle Research and Test Center in East Liberty, Ohio. (Further analysis of the 95th percentile male which is based upon computer analysis is presented in Section 5 of this report).

3. The Phase III sled Tests demonstrated that the present ACRS design for the right front passenger is capable of protecting the size range of 5th percentile female through 50th percentile male at frontal impact velocities of at least 35 mph (the maximum velocity tested in the sled test series) with injury measures substantially below the crieria limits.

   The Phase I vehicle crash with a 50th percentile male passenger ATD showed that the impact velocity may be increased beyond 40 mph with the passenger still receiving injury measures well below the criteria limits.

   The comments in item "2" above pertaining to the 95th percentile male driver apply equally well to the 95th percentile male passenger also.

   For the three year old, forward positioned child tested in the computer selected "critical" condition of seated, 4 to 7 inches chest-to-airbag distance, and undergoing a crash

of 30 mph or greater, the HIC and chest g's were below the criteria limits although chest g's were marginal. The chest g's were 59 g's in both sled tests with the final system configuration (Test Nos. 11 and 12).

However, as pointed out on page 4-70, pages 4-19 to 4-21 and then proven in Appendix B; the 3 year old dummy used ir these tests is an anomaly. To reiterate, the plastic dummy head in combination with the accelerometer mount used in this particular dummy caused a severe vibratory response to be set up in all three channels of the dummy head during and after the period of bagslap. In checking other dummy sizes whose heads were excited by an impulsive load, the three year old dummy size was the only one to exhibit this virtually undamped type of response (see Appendix B).

The dummy chest behaved in much the same way, although to a slightly lesser degree. Again, an oscillatory, virtually undamped vibration was set up during and slightly after bagslap - this time in the chest cavity. We estimate, based upon drawing a line through the midpoints of the data excursions shown on pages A-295 through A-298 and A-313 through A-316 for Test Nos. 11 and 12 respectively, that the chest g's would have been lower by approximately 9 g's had it not been for this resonant effect.

4. The systems analysis approach to design as described on page 1-1 has been shown to be a very cost and time effective method of developing production level, airbag restraint systems. We say this for several reasons which are enumerated on the following page.

a) With no preliminary testing, the systems analysis approach led to a computer derived design of both the driver and passenger airbag restraint systems which proved capable of protecting the driver and passenger to the extent that they received injury measures substantially below the crieria limits in two separate frontal crashes at 36 and 41 mph respectively (50^{th} percentile dummy sizes were used in these tests).

b) Sled Tests conducted subsequent to the crash tests showed these same computer derived systems capable of protecting the complete size range potential drivers and passengers within the injury criteria limits up to and beyond 35 mph (with the exception of the 95^{th} percentile male which could not be tested due to lack of headroom in the sled compartment; see (c) below for more details).

c) Computer simulations conducted subsequent to the sled tests indicated that the 95^{th} percentile male driver and passenger would also meet the injury criteria limits in the actual DeLorean vehicle assuming the header rotates upward and forward as it did in the two barrier crashes (see Section 5.2) so the passenger head would not impact the header.

d) The original design which was first used in the Phase I barrier crash tests and derived via compter using the systems analysis approach, remained virtually unchanged throughout subsequent simulations and sled testing. We believe this shows the strengh of the original design which was based upon this approach.

The only change[1] made to the design after these initial simulations and crash tests was to the method of folding the passenger airbag. In this case the bag fold was changed from an "accordian fold" to a "rolled under" type of fold. This sole change was made to a part of the system not simulated in the computer models used and was done to lower the HIC on the forward positioned child by allowing the bag to deploy lower on the child.

Recommendations

1. We recommend that the restraint system designs for the driver and passenger as summarized in Section 2.2 of this report be adopted as the pre-production prototypes for the DeLorean Sports Car. We further believe that the methodology presented in this report could be applied to any car to develop an optimally performing restraint system. In fact it is here that we believe the true strength of the systems analysis approach lies.

   We further believe that with the necessary "tuning" modifications which could largely be done through computer techniques developed during this program, these same basic systems would perform well in other small production cars. We recommend that this theory be verified in future NHTSA programs using a small production vehicle of NHTSA's choice.

2. We recommend that NHTSA investigate to see whether other contractors have experienced the problem of severe oscillatory head and chest response using the three year old size Alderson dummy. If so, we believe that this dummy should be

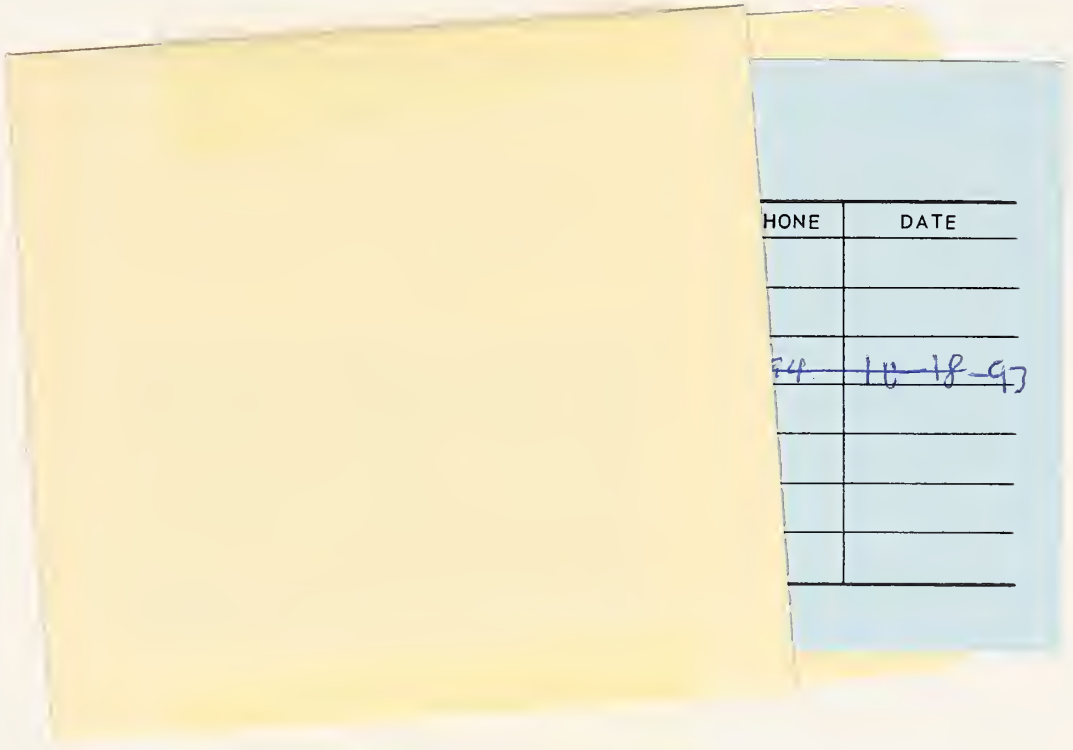
[1] A second change was made to the driver system following the crash tests. In the crash tests the steering wheel spokes were stiffened. This later proved unnecessary and was not done in the Phase II simulations or the Phase III sled tests.

modified to eliminate this type of undamped response which is unlike the human equivalent. As our data in Appendix B shows, the three year old dummy is the only dummy that behaves this way. Since this dummy size is the one most likely to be tested in an environment where impulsive loads such as bagslap are encountered, it is especially important that it be a reliable indicator of actual child chest response so it can exhibit the fidelity required to make judgements associated with restraint system design.

3. It is recommended that further research be done to derive a reliable sensor for the DeLorean. Up until now, with the emphasis on airbag design parameters, the airbags have been initiated with a simple electronic delay circuit based upon bumper contact. Actual sensors have only been employed in "piggyback" fashion in order to obtain information without risking the fire or non-fire of the airbags upon an unproven sensor.

   However now that we have determined the necessary sensing time of 15 msec or less for the primary firing and the 7 msec delay after the primary firing for the initiation of the second passenger inflator, additional crash testing with a production sensor of the Bosche type (or similar design) should be done to complete the design process. If not done for the DeLorean, perhaps this additional testing could be done for some other small production car in a future program.

This completes our report on the pertinent developments of this project. Fitzpatrick Engineering is grateful to NHTSA for the opportunity to demonstrate the systems analysis approach to restraint systems design and to show a method of combining test with computer simulation to achieve the program goals.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